

Open Research Online

The Open University's repository of research publications and other research outputs

Fidelity and complexity : aspects of reality in interactive learning environments for physics learners

Thesis

How to cite:

Hatzipanagos, Stylianos (1998). Fidelity and complexity : aspects of reality in interactive learning environments for physics learners. PhD thesis The Open University.

For guidance on citations see [FAQs](#).

© 1998 The Author



<https://creativecommons.org/licenses/by-nc-nd/4.0/>

Version: Version of Record

Link(s) to article on publisher's website:

<http://dx.doi.org/doi:10.21954/ou.ro.0000dc91>

Copyright and Moral Rights for the articles on this site are retained by the individual authors and/or other copyright owners. For more information on Open Research Online's data [policy](#) on reuse of materials please consult the policies page.

oro.open.ac.uk

Fidelity and Complexity: Aspects of Reality in Interactive Learning Environments for Physics Learners

Stylios Hatzipanagos

**Submitted for the degree of Doctor of Philosophy
in Educational Technology**

**Institute of Educational Technology
Milton Keynes**

December 1998

The Open University

IMAGING SERVICES NORTH

Boston Spa, Wetherby

West Yorkshire, LS23 7BQ

www.bl.uk

ORIGINAL COPY TIGHTLY
BOUND

**PAGINATED BLANK PAGES
ARE SCANNED AS FOUND
IN ORIGINAL THESIS**

**NO INFORMATION IS
MISSING**

Thesis Abstract

Computer-based interactive learning environments in physics can help students to differentiate between their intuitive views on natural phenomena and the formalisms of Newtonian physics. This thesis describes empirical investigations of a specific type of interactive learning environments, computer-based simulations. In many cases computer simulations deal with a simplified and idealised version of the natural phenomenon. Presenting the user with a simplification of reality is seen as one of the advantages of simulations, since too complex and too realistic simulations may sometimes be overwhelming for learners and may not permit the identification of the underlying model. Yet implications arise about the degree to which students either expect or perceive simulations to be real and how these expectations and perceptions affect their interaction with the simulation.

Reality for the purposes of this research is considered to be a construct comprising the visual fidelity (fidelity) and the complexity of the underlying physical model (complexity) of the simulation. Evaluation of a number of simulations, two case studies and interviews with simulation designers and educators suggested these components. **Altering the relation between fidelity and complexity levels affects students' learning and contributes to the students' perception of reality.** This is demonstrated in a study of a number of simulations of the same physical phenomenon (Newtonian collisions) with degrees of fidelity and complexity which have been examined to test this hypothesis. Two empirical studies were then conducted to investigate the use of simulations which represented different fidelity and complexity levels.

Analyses were carried out on videotapes and questionnaires of students interacting collaboratively with the simulations (40 hours of computer based activity). The empirical approaches to these studies, reports on work done, including the emerging data in multiple forms (questionnaires, video and audio tapes of the students interaction) and its analysis are presented in this thesis. The work reported looks at students' interaction with the simulations (pre to post test learning

gain and issues concerning pre and post testing), their comments on the interface and the model underlying the simulation.

The thesis supports the view that well designed computer-based simulations can promote learning and that design issues are essential to the creation of successful simulations. The findings claim that:

- a) enhanced fidelity of an instructional simulation has positive effects on the learner outcome,
- b) interfaces which use multiple representations offer valuable information which facilitates problem solving strategies and
- c) low complexity simulations are better suited to novice learners.

These outcomes are presented as implications for simulation design and the use and development of a syntax in simulation design is also discussed (design criteria for how systems might be built). Finally the outcomes' applicability, the limitations of the studies, as well as the scope for further research that should lead to an understanding of the factors which promote successful use of simulations in the teaching of physics are presented.

Acknowledgements

This thesis would not have reached completion without the continuous help and encouragement of both my supervisors, Eileen Scanlon and Barbara Hodgson. They were always there for me whenever I needed their support with fresh ideas and very useful feedback.

I'd also like to say a big "thank you" to the people who provided feedback on the first draft: Tammy Sumner for her enthusiasm and all the useful references; Denise Whitelock who encouraged me to rethink some aspects of the thesis; Teresa del Soldato who was more than generous in her comments; Martin Oliver for lots of insightful stylistic and content suggestions; Rupert Wegeriff (who read two chapters) for his very thorough feedback and philosophical approach to the issues of my research. Also Evita Alexopoulos for her intuitive comments on style and structure.

I would like to thank all the people whose comments and feedback had an impact on aspects of this thesis and particularly the people from the university of Crete, the people from the HCI97 doctoral workshop, especially Angela Sasse, who advised me on the HCI aspect of the thesis and also Janet McCracken. Also Erica Morris and Karen Vines for their valuable advice on the thesis' statistics. Also the teachers and students from the schools in Buckinghamshire, Ipswich and London where the observation studies took place, particularly, Gareth Hodges, Vince Piper, Peter Malone, Judy Michin and Rosina Oliver.

I am also most grateful to Evita, Madeline, Iraklis, Olabisi, Erica, Jane, Piers and my other friends at the Open University, in England and in Greece for their faith in my academic abilities, their "counselling" and words of wisdom, when things were not as bright. Also to Buddy for his help with what proved to be the only dull activity of this research: helping with the transcription of some of the video and audio tapes, when "estuary" English was too much for me.

Finally a big thanks to my mother whose "down to earth" philosophy of life put everything in context.

People have a faculty of graphical intuition and things are seen more clearly if they are represented graphically. If a picture is worth a thousand words, a moving picture is worth a thousand static ones and a dynamic picture that you can interact with is worth a thousand movies.

Andries van Dam

DATA CODE

Sources

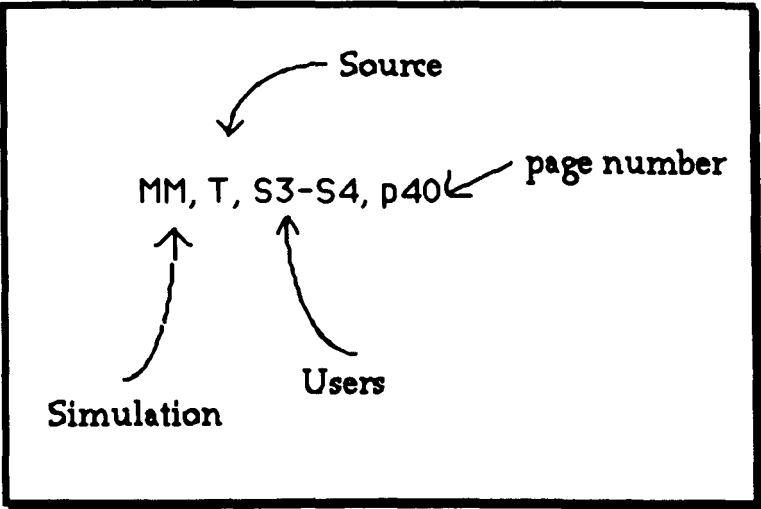
- Q1: Answers to the pre test questionnaire
- W: Worksheets
- Q2: Answers to the post test questionnaire
- T: Interaction Transcripts
- IT: Interview Transcripts

Simulations

- MM: Multimedia Motion
- CoC: ColaCollision
- CC: CirclesColliding
- DM³: Direct Manipulation of Mechanics Microworlds

Users

- | | |
|-----------------|---------------|
| Pilot study: | P1,....., P9 |
| Ch4 interviews: | 1,.....,10 |
| CoC study: | P10.....,P17 |
| MM, CC studies: | S1,....., S26 |



Contents

| | |
|---|-----------|
| Chapter One: Introduction..... | 1 |
| Overview of the thesis..... | 6 |
| Chapter Two: Literature Review | 11 |
| 2.1. Introduction | 11 |
| 2.2. Physics education and the teaching of mechanics | 11 |
| 2.3. Computer assisted learning | 14 |
| 2.4. Simulations..... | 17 |
| 2.5. Microworlds and simulations..... | 20 |
| 2.6. The use of simulations in an instructional context..... | 22 |
| 2.6.1. Simulations and practical work..... | 22 |
| 2.6.2. Simulations as part of a teaching/learning cycle | 24 |
| 2.7. Taxonomy of science simulations..... | 25 |
| 2.7.1. Underlying model..... | 29 |
| 2.7.2. Visual representation and interface..... | 29 |
| 2.7.3. Motivation..... | 30 |
| 2.7.4. Representation of reality | 32 |
| 2.8. Review of simulations..... | 33 |
| 2.8.1. Puckland..... | 34 |
| 2.8.2. Gravitas | 36 |
| 2.8.3. Friction Worlds | 39 |
| 2.8.4. DM3 scenarios..... | 41 |
| 2.8.5. Multimedia Motion..... | 44 |
| 2.9. Conclusion..... | 47 |
| Chapter Three: Pilot Study..... | 51 |
| 3.1. Introduction | 51 |
| 3.2. Aim of the study..... | 52 |
| 3.3. Participants | 52 |
| 3.3. Procedure | 54 |
| 3.4. Description of the questionnaires..... | 54 |
| 3.5. Gravitas | 56 |
| 3.5.1. Questionnaires and worksheet | 56 |
| 3.5.2. The Task..... | 57 |
| 3.5.3. Creating a MassOb System, P2: Ben..... | 61 |
| 3.5.4. Creating a MassOb system, P3: Brenda..... | 65 |
| 3.6. Multimedia Motion..... | 70 |
| 3.6.1. Questionnaires..... | 70 |
| 3.6.2. The worksheet and the tasks | 71 |
| The simulated lab, P5: Li and P6: Darren | 72 |
| The simulated lab, P7, P8, P9: Gabriel, John and Steve..... | 74 |
| 3.7. Findings from the study: Reality and Underlying model..... | 77 |
| 3.7.1. Analysis of attitudes to the simulations | 77 |
| 3.7.2. Interface..... | 78 |
| 3.7.3. Underlying model..... | 80 |
| 3.8. Conclusion..... | 80 |

| | |
|---|------------|
| Chapter Four: Fidelity and complexity | 85 |
| 4.1. Introduction | 85 |
| 4.2. Fidelity theories | 86 |
| 4.2.1. Allen: Training simulator fidelity | 87 |
| 4.2.2. Wenger: Epistemic fidelity | 87 |
| 4.2.3. Roschelle: Mediating Collaborative Inquiry versus Epistemic fidelity | 89 |
| 4.2.4. De Hoog: Input and output fidelity | 90 |
| 4.2.5. Alessi: taxonomy of fidelity considerations | 91 |
| 4.3. Research on the relationship between fidelity and learning | 92 |
| 4.3.1. High fidelity: research evidence | 93 |
| 4.3.2. Low fidelity: research evidence | 95 |
| 4.4. Fidelity and complexity as dimensions of the perceived reality | 95 |
| 4.4.1. Fidelity | 96 |
| 4.4.2. Complexity | 98 |
| 4.5. Coordinates of reality or the simulation map | 99 |
| 4.6. Interviews | 102 |
| 4.6.1. Design features of a successful simulation: clarity and ease of use | 104 |
| 4.6.2. Degree of realism in a simulation | 105 |
| 4.6.3. Simulations' bibliography, choice of successful simulations | 106 |
| 4.6.4. High fidelity interfaces and student understanding | 108 |
| 4.6.5. The "transparent" interface and the underlying model | 109 |
| 4.6.6. Fidelity and the knowledge level of the learner | 110 |
| 4.6.7. Time fidelity in simulations | 111 |
| 4.6.8. High fidelity and motivation | 111 |
| 4.6.9. Shifting levels of fidelity and complexity | 112 |
| 4.6.10. Fidelity and "hands on" instruction | 113 |
| 4.6.11. Relation between fidelity and the domain | 114 |
| 4.6.12. What combination of fidelity and complexity | 114 |
| 4.7. Conclusion | 115 |
| Chapter Five: The ColaCollision study | 117 |
| 5.1. Introduction | 117 |
| 5.2. The Study | 118 |
| 5.2.1. The CoC software | 118 |
| 5.2.2. Subjects and procedure | 120 |
| 5.2.3. Description of the worksheet: the task | 122 |
| 5.3. Data analysis | 123 |
| 5.3.1. Questionnaire analysis | 123 |
| Previous experience with computers | 123 |
| Previous knowledge of simulations | 123 |
| Pre and post test comparison outcomes | 123 |
| 5.3.2. Discussion of pairs: pre to post gain and interaction | 127 |
| P10, P11: Vanessa and Derek | 127 |

| | |
|--|------------|
| P12, P13: Harry and Mick | 130 |
| P14, P15: Elisa and Sara..... | 137 |
| 5.3.3. Observational data | 141 |
| 5.4. Findings of the study | 142 |
| 5.5. Conclusion..... | 144 |
| Chapter Six: Design and Methodology | 147 |
| 6.1. Introduction | 147 |
| 6.2. Research hypothesis | 148 |
| 6.3. Aim and procedure of the studies..... | 151 |
| 6.3.1. Learning about collisions | 153 |
| 6.3.2. Choice of simulations | 156 |
| Multimedia Motion (MM)..... | 156 |
| CirclesColliding (CC) | 159 |
| 6.3.3. Design of questionnaires | 164 |
| Post-test questionnaires | 165 |
| 6.3.4. Interaction with the simulation | 165 |
| 6.3.5. Nature of the tasks..... | 167 |
| 6.3.6. Interviews..... | 167 |
| 6.4. Data analysis..... | 168 |
| 6.4.1. Learning and usability..... | 170 |
| 6.5. Conclusion..... | 172 |
| Chapter Seven: The Multimedia Motion study: working with a high fidelity, low complexity simulation | 173 |
| 7.1. Introduction | 173 |
| 7.2. The Study | 173 |
| 7.2.1. Subjects and procedure | 173 |
| 7.2.2. The MM sequences | 176 |
| 7.2.3. Description of the worksheet: the tasks..... | 178 |
| 7.3. Data analysis..... | 181 |
| 7.3.1. Questionnaire analysis..... | 181 |
| Previous experience with computers | 181 |
| Science courses in school..... | 182 |
| Mathematics courses in school | 182 |
| Previous knowledge of simulations..... | 182 |
| Pre and post test comparison outcomes..... | 183 |
| 7.3.2. Discussion of pairs, pre to post gain and interaction..... | 188 |
| S1,S2: Daniel and Robert..... | 189 |
| S3,S4: Barry and Judith..... | 196 |
| S9, S10: Roger and Ray. | 201 |
| 7.3.3. Observational data | 206 |
| 7.4. Findings of the study | 208 |
| 7.5. Conclusion..... | 211 |
| Chapter Eight: The CirclesColliding study: working with a low fidelity, low complexity simulation | 213 |
| 8.1. Introduction | 213 |
| 8.2. The Study | 213 |

| | |
|--|-----|
| 8.2.1. Subjects and procedure..... | 213 |
| 8.2.2. The CC1 sequences..... | 215 |
| 8.2.3. Description of the worksheet: the tasks | 217 |
| 8.3. Data analysis..... | 219 |
| 8.3.1. Questionnaire analysis | 219 |
| Previous experience with computers..... | 219 |
| Science courses in school..... | 219 |
| Mathematics courses in school..... | 220 |
| Previous knowledge of simulations..... | 220 |
| Pre and post test comparisons..... | 220 |
| 8.3.2. Discussion of pairs, pre to post gain and interaction | 224 |
| S15, S16: Martin and Anthony | 225 |
| S19, S20: Gordon and Peter | 230 |
| S23, S24: Philip and Nigel | 234 |
| 8.3.3. The CC2 simulation | 239 |
| 8.3.4. Observational data..... | 242 |
| 8.4. Findings of the study..... | 242 |
| 8.5. Conclusion | 244 |

Chapter Nine: Comparison of the studies and investigating

| | |
|--|------------|
| usability in both simulations | 247 |
| 9.1. Introduction..... | 247 |
| 9.2. Comparison between the learning environments..... | 248 |
| 9.3. Usability study | 253 |
| 9.3.1. Subjects and procedure..... | 253 |
| 9.3.2. Questionnaires | 254 |
| 9.3.3. Interviews..... | 255 |
| 9.3.4. User satisfaction | 256 |
| Perception of performance..... | 256 |
| Perception of software effectiveness..... | 257 |
| 9.3.4. Qualitative analysis: results..... | 261 |
| Comparison with alternative learning experiences..... | 261 |
| Realism versus abstraction..... | 263 |
| Interface..... | 267 |
| Graphs | 268 |
| 9.4. Conclusion | 272 |

| | |
|---|------------|
| Chapter Ten: Conclusions..... | 275 |
| 10.1. Introduction..... | 275 |
| 10.2. Findings from the studies..... | 275 |
| 10.2.1. Enhanced fidelity level..... | 276 |
| 10.2.2. Multiple representations..... | 277 |
| 10.2.3. Complexity level of simulations..... | 279 |
| 10.3. Design criteria: a syntax for physics simulations | 281 |
| 10.3.1. High fidelity representations..... | 281 |
| 10.3.2. Fidelity sequences | 282 |
| 10.3.3. Real time..... | 282 |
| 10.3.4. Interface syntax..... | 283 |
| Graphs | 283 |

| | |
|---|-----|
| Fields vs gliders | 284 |
| Size of the screen..... | 284 |
| Revisiting the simulation..... | 285 |
| Database..... | 285 |
| 10.4. Contributions and achievements..... | 286 |
| 10.5. Limitations and Criticisms..... | 291 |
| 10.6. Further scope..... | 292 |
| 10.6.1. Student modelling..... | 292 |
| 10.6.2. Sequences of simulations..... | 292 |
| 10.6.3. Alternate realities..... | 294 |
| 10.6.4. Interface syntax | 295 |
| 10.7. Summary | 296 |

References

Participants of the case studies

Appendix 1, Questionnaires and worksheets

Appendix 2, Gravitas, MM-pilot

Appendix 3, ColaCollision

Appendix 4, Multimedia Motion

Appendix 5, CirclesColliding

Appendix 6, Worksheet tasks: solutions

Appendix 7, Chapter Four Interviews

INDEX OF FIGURES

Fig 2.1. Puckland.

Fig 2.2. Gravitas.

Fig 2.3. Friction Worlds.

Fig 2.4. DM³.

Fig 2.5. Multimedia Motion: interface.

Fig. 3.1. Orbital Procession.

Fig 3.2. MM: Soccer.

Fig. 4.1. Hypothesised relationship of fidelity and learning for novice students, Alessi (1988).

Fig 4.2. Image types (Whalley, 1995).

Fig 4.3. Simulations of Chapter Two on the Fidelity Complexity space.

Fig 4.4. ColaCollision.

Fig. 4.5. An Interactive Physics (IP) simulation.

Fig. 5.1. ColaCollision: interface.

Fig. 5.2. Condition 1.

Fig. 5.3. Condition 2.

Fig. 5.4. Condition 3.

Fig. 5.5. Pre to post test percentages of correct answers.

Fig 6.1. Overview of the research hypothesis development.

Fig 6.2. Multimedia Motion: interface.

Fig. 6.3. Image types (Whalley, 1995).

Fig 6.4. Multimedia Motion: spreadsheet.

Fig 6.5. Multimedia Motion: velocity graph.

Fig 6.6. CirclesColliding1 (CC1).

Fig 6.7. CirclesColliding2 (CC2).

Fig 7.1. Multimedia Motion (Collision 1).

Fig 7.2. Multimedia Motion (Collision 4).

Fig 7.3. Multimedia Motion (Collision 5).

Fig 7.4. Condition 1.

Fig 7.5. Condition 2.

Fig 7.6. Condition 3.

Fig 7.7. Pre to post test percentages of correct answers.

Fig 8.1. CC1 (Collision 1).

Fig 8.2. CC1 (Collision 2).

Fig 8.3. CC1 (Collision 3).

Fig 8.4. Pre to post test percentages of correct answers.

Fig 8.5. The CC2 worksheet prediction.

Fig 9.1. Comparison between percentages of correct answers in MM and CC1.

INDEX OF TABLES

Table 1.1. Research timetable.

Table 2. 1. Arguments in favour and against simulations.

Table 2.2. Taxonomy of simulations (Hatzipanagos, 1995).

Table 2.3. Taxonomies of simulations.

Table 3.1. Previous knowledge of simulations.

Table 3.2. Users in the pilot study.

Table 3.3. Time length of interactions with Gravitas.

Table 3.4. Observation schedule of Ben for Gravitas.

Table 3.5. Observation schedule of Brenda for Gravitas.

Table 3.6. Time length of interactions with Multimedia Motion.

Table 3.7. Observation schedule of Li and Darren for Multimedia Motion.

Table 3.8. Observation schedule of Gabriel, John and Steve for Multimedia Motion.

Table 4.1. Fidelity theories

Table 4.2. Alessi's taxonomy of physical simulations

Table 4.3. Simulations of Chapter 1 checked against the fidelity definition.

Table 5.1. Gender distribution in participants' pairs.

Table 5. 2. Time taken for CoC interactions.

Table 5.3. Previous experience with computers.

Table 5.4. CoC pre to post test shift.

Table 5.5. CoC, Pre and Post test: Percentage of correct answers.

Table 5.6. Wilcoxon test for CoC .

Table 5.7. P10, P11: pre to post test shift.

Table 5.8. Observation schedule of Vanessa and Derek for ColaCollision.

Table 5.9. CoC pre to post test shift.

Table 5.10. Observation schedule of Harry and Mick for ColaCollision.

Table 5.11. CoC pre to post test shift.

Table 5.12. Observation schedule of Elisa and Sara for ColaCollision.

Table 5.13. Characteristics of ColaCollision.

Table 6.1. Outline of the data collection procedures used in the studies.

Table 6.2. Comparison of spontaneous and disciplinary frameworks in mechanics.

Table 6.3. Spontaneous and disciplinary perspective in mechanical collisions.

Table 6.4. Simulations on the fidelity-complexity space.

Table 6.5. Outline of the studies.

Table 5.4. Outline of the studies.

Table 6.6. Classification of outcomes.

Table 6.7. Usability measures.

Table 7.1. Gender distribution in student's' pairs

Table 7. 2. Time taken by each pair working with the simulation.

Table 7.3. MM: Previous experience with computers.

Table 7.4. MM: Science courses in school.

Table 7.5. MM: Mathematics courses in school.

Table 7.6. MM: Previous knowledge of simulations

Table 7.7. MM-pre to post test shift.

Table 7.8. MM, Preliminary and post test: Percentage of correct answers.

Table 7.9. Wilcoxon test for MM.

Table 7.10. MM: McNemar's test.

Table 7.11. Pair S1, S2, predictions.

Table 7.12: Observation schedule of students S1: Robert and S2: Daniel

Table 7.13. Pair S3, S4, predictions

Table 7.14: Observation schedule of students S3: Barry, and S4: Judith

Table 7.15. Pair S9, S10, predictions.

Table 7.16: Observation schedule of students S9: Roger and S10: Ray

Table 8.1. Gender distribution in participating students.

Table 8. 2. Time taken by each pair working with the simulation.

Table 8.3. CC1: Previous experience with computers.

Table 8.4. CC1: Science courses in school.

Table 8.5. CC1: Mathematics courses in school.

Table 8.6. CC1: Previous knowledge of simulations.

Table 8.7. CC1 pre to post test shift.

Table 8.8. CC1, Preliminary and post test: Percentage of correct answers.

Table 8.9. Wilcoxon test for CC1.

Table 8.10. CC1: McNemar's test.

Table 8.11. Pair S15, S16: pre and post test predictions

Table 8.12: Observation schedule of students S15: Anthony and S16: Martin

Table 8.13. Pair S19 S20, predictions

Table 8.14: Observation schedule of students S19: Gordon and S20: Peter

Table 8.15. Pair S23,S24, predictions

Table 8.16: Observation schedule of students S23: Philip and S24: Nigel

Table 9.1. MM and CC1, Post test: Percentage of correct answers.

Table 9.2. Comparison of simulations: Multimedia Motion and CirclesColliding.

Table 9.3. MM: user satisfaction with performance

Table 9.4. CC1: user satisfaction with their performance.

Table 9.5. MM: percentage of users who find the MM software effective.

Table 9.6. CC1: percentage of users who found the software effective.

Table 10.1. Summary of the contributions of this thesis.

Table 10.2. Four categories of fidelity complexity simulations.

Table 10.3. Examples of sequences of simulation from Table 10.2.

Chapter One

Introduction

This thesis is the result of research carried out in the Institute of Educational Technology at the Open University. Having completed a first degree in Physics in Greece, I worked in Greek secondary and further education, teaching physics and mathematics. I came to Britain in 1991 to study at a postgraduate level. My interests were in science education and the use of computers for educational purposes. I chose to do an MSc in physics education in Reading University. The MSc's theoretical component dealt with philosophy of education, science education and theories of cognition, while the dissertation attempted a comparison of the 16-19 physics education in Greece and in England and highlighted differences of educational practices in the teaching of physics in the two countries (Hatzipanagos, 1992).

A second MSc in Information Technology and its applications to language generation in South Bank University in London comprised components on the use of Multimedia for representing knowledge with an emphasis on interface design. It also instigated my interest in how computers can assist learning and specifically in computer based learning environments.

The next step was starting my doctoral research whose focus was computer simulations and the rich field of their applications in science education. Simulations allow learners to engage in their own problems by providing contextualised support and by exploiting "breakdowns" (Fischer & Scharff, 1997) as opportunities for learning.

After scanning the literature on interactive learning environments, I attempted a classification of simulations in relation to the issues that I considered important. Simulations represent natural phenomena which are formalised into a model and implemented as a computer program. The model is often created by a designer/programmer based on the underlying scientific theory. It is later explored by students who can interact with this model by changing the conditions and variables and immediately visualising the consequences of such manipulation. My initial approach included some empirical investigation of computer-based interactive learning environments, the majority of which were simulations. My experience of teaching also helped to set some realistic objectives in experimental studies. The preliminary empirical studies of users interacting with a number of simulations highlighted some general issues. Two issues emerged as most interesting for describing aspects of simulations in physics: the **underlying model**, of which the students can catch a glimpse, either indirectly by observing the objects of the simulation in motion, or directly by taking into account the expression of variables into spreadsheets, digital counters, graphs and how this underlying model is represented in the **interface**. The interface, as a visual representation of the physical reality, constitutes the medium between this physical reality and the user. In collaborative interactions of this type, the learners have to negotiate their understanding between them and with the computer.

Next, theories which described how a simulation imitated reality were examined. It seemed that an appropriate classification of learning environments (for the purposes of this research) would be in terms of

fidelity and complexity, two variables describing the verisimilitude of the interface and the degree of sophistication of the underlying model.

On the basis of this rationale an overall statement of a research hypothesis was proposed:

Altering the fidelity level of a simulation and the relation between this fidelity and the complexity of the underlying model affects students' conceptual learning and contributes to the students' perception of reality.

The full consequences and implications of this general statement were outside the limits of this research, during the period of study for a PhD. Consequently this overall statement was broken down into three specific statements (see 6.2). The particular statements referred to high fidelity simulations, to low complexity ones and to the use of multiple representations in the interface's design.

The next stage involved learners in empirical studies testing hypotheses to explore this relationship between fidelity and complexity using a number of simulations. The simulations were different representations of physical reality, dealing with the same phenomenon with different degrees of fidelity and complexity. Newtonian mechanics was chosen as the content area to explore because it is an important area of physics in which many students have difficulty visualising aspects of phenomena and predicting outcomes. Also the use of mechanics (e.g. visualising motion) takes advantage of the computer's graphics and interactive capabilities. The

learning environments involved simulations which displayed collision of masses on a screen.

The intention was to analyse in depth how students attempt to construct knowledge. The technique used was videotaping the output of the computer monitor and at the same time recording their comments. The advantage of using a technique like this is that the interaction can be analysed together with the questionnaires and worksheets the students completed.

The empirical studies indicated that collaborative schemes or an instructional cycle (see 3.8) were the route to follow for optimisation of the interaction. Also, the use of simulations facilitated learning and the design of computer based environments in physics can influence the users' perception of the physical phenomena they represent. The central hypothesis also impinges upon the design process of interactive computer learning environments. The production of successful simulations is intrinsically connected with the use of carefully designed software. The research was planned to investigate what design issues are essential to the creation of successful simulations, thus exploring the implications for design and discussing the development of design criteria for how simulations might be built.

The central idea behind this research is that well designed computer-based simulations can promote learning. An appropriate design can enhance the functionality of the interface and also the overall usability of the simulations. However, evaluating these environments by applying strictly usability criteria would not take

into account that usability for computer based instruction is probably a wider issue than directives for simplicity and ease of use. Recent research has indicated (Rappin, 1997) that simplicity is not always the desired aim in designing educational software, since cognitive obstacles might give the opportunity to the learners to explore a piece of software more exhaustively and learn from it.

A timetable of this research is presented in Table 1.1.

| | |
|-----------------------------|--|
| October 1993-September 1994 | Annotated literature review. Review of simulations: Puckland, Gravitas, Friction worlds, DM ³ , Multimedia Motion. Pilot study: Gravitas and Multimedia Motion. Research proposal. |
| October 1994-September 1995 | Fidelity-complexity theory. Case study with educators/designers. Design of ColaCollision simulation. ColaCollision study. |
| October 1995-September 1996 | Design of main study. Design and implementation of CirclesColliding simulations. Main study: Multimedia Motion and CirclesColliding. |
| October 1996-September 1997 | Main study: CirclesColliding. Thesis write-up, first draft. |
| October 1997-September 1998 | Thesis write-up. |

Table 1.1. Research timetable.

Finally it should be stressed that this research focuses on Advanced Level physics students. Simulations can be used by a wide range of students from elementary school to university level since one of the

advantages of educational software is that a wide range of learners are able to use the same software, with the use of appropriate tasks. As Thornton (1992) points out, the tools do not dictate the phenomena to be investigated, the steps of the investigation, or the level or sophistication of the curriculum.

Overview of the thesis

Chapter Two is a review of the literature on using simulations to teach physics together with a review of a number of simulations. A brief introduction on physics education is followed by an overview of computer assisted learning (CAL) and a detailed analysis of simulations as educational software. Next a discussion of simulation design and the attributes which contribute to successful use is followed by a review of a number of simulations. The chapter ends with a general overview of the use of simulations in the classroom and laboratory.

Chapter Three describes observations of learners using two computer simulations. Both represent a physical phenomenon and could be used effectively in an instructional context; consequently they were considered to be appropriate candidates for this kind of investigation: Gravitas and Multimedia Motion. A detailed description of the structure of the study (participants and aims) is presented, followed by an outline of the procedure. A brief overview of the software used for each simulation and the analysis of the questionnaires and video taped data is described. The main findings are given and results on the simulations' usability are also outlined. The findings from these studies led the research towards a theory of the simulation interface

and underlying model, which in its turn led to the fidelity-complexity approach of classifying computer simulations, described in Chapter Four.

Chapter Four begins with an overview of the two variables, fidelity and complexity, which are described in detail and applied to the simulations already described in Chapter Two. This is followed by a set of interviews with teachers and software designers, in which interfaces were evaluated and the choice of appropriate degrees of fidelity and complexity in the design of computer simulations was discussed.

In **Chapter Five** observations of learners using another simulation, ColaCollision are described. The intention was to apply the theoretical framework of Chapter Four on an interactive learning environment and also test an evaluation methodology which would ideally extract appropriate data for this research. After an outline of the procedure, a description of the study (participants, aims and annotated interactions) follows. The findings are given and suggestions are discussed for an evaluation methodology which would ideally extract appropriate data for this research, as well as for a methodological approach combining quantitative and qualitative data analysis.

In **Chapter Six** a rationale of the research which led to the research hypothesis will be discussed. It is followed by a discussion on the choice of appropriate methodology. The data analysis method used is also described and there is a discussion of the merits of such analysis compared to other methods, based on Chapters Three, Four and Five.

In **Chapter Seven and Eight** observations of learners using simulations are described, representing different degrees of fidelity and complexity. In Chapter Seven, Multimedia Motion (MM) represents high fidelity and low complexity. Chapter Eight describes observations with learners using the CirclesColliding (CC1) simulation, representing low fidelity and low complexity. The same technique of videotaping the output of the computer monitor and at the same time recording the student's comments was followed. The emphasis was on the analysis of the questionnaires and video taped data of the actual interaction. An analysis of the procedure is followed by a detailed description of each study (participants, aims, annotated interactions). The findings are given and a connection is made to the main threads of this research.

In **Chapter Nine** a comparison is made between Multimedia Motion and CirclesColliding, in terms of the features of each simulation. The chapter also examines a different aspect of the collected data, drawing from completed questionnaires and semi-structured interviews, where the users described their experience with the simulations. It is an examination of the data in terms of people's behaviour and users' perception of what they think they did. This part of the investigation examined how users reacted to the design of the interface and it kept track of their reaction to the features of the simulation, and also their attitudes.

In **Chapter Ten** the original research question is considered in the light of the findings. The claim of the thesis is that it has contributed to a better understanding of the factors which promote successful use of educational software in teaching physics. This claim is examined in

detail. The outcomes of the studies are presented and implications for simulation design are examined, followed by a discussion of design criteria for how systems might be built. The discussion of the outcomes is followed by a critique of their applicability, limitations and criticisms and finally the scope for further research.

Chapter Two

Literature Review

2.1. Introduction

The chapter provides an introduction to the recurring issues in this research, namely science and physics education, computer assisted learning (CAL) and in particular computer simulations as interactive learning environments. The literature on interactive learning environments is surveyed and a classification is attempted of simulations in relation to their components which support effective use by learners. Next, a general overview of the use of simulations in the science classroom and laboratory is presented, followed by a discussion of simulation design and the attributes which enhance successful use. The chapter ends with a review of a number of simulations.

2.2. Physics education and the teaching of mechanics

Science teaching aims to provide students with a knowledge of the nature of the universe. An important aspect of this teaching is that students must forsake their intuitive views (individual frameworks) on natural phenomena. In any educational course, a typical objective, according to Christel (1994), is also to provide the learner with a better appreciation of the domain being taught, so that the learner will be willing and able to apply the subject matter to problems long after the course has finished. Certainly this applies to science too, where the

objective is to encourage students to apply things learned in the classroom to new situations.

Much of the research in science education is concerned with the lack of understanding of scientific concepts by school and university students (Driver, 1989). There is an extensive literature that indicates that learners come to their science classes with prior or "naive" conceptions that may differ substantially from the ideas to be taught, that these conceptions influence further learning and that they may be resistant to change (ibid.). In science education, therefore, the emphasis is on "conceptual change" (White & Gunstone, 1989), which is the term popularly used for the replacement of naive beliefs about natural and social phenomena by more sophisticated ones.

Various reasons have been given for students' difficulties with physics. Champagne *et al*, (1980) refer to a list of the more often explored variables that contribute to students' success in learning physics: mathematical skills, general level of cognitive development, specific cognitive processes, content preconceptions. Motivation can also be added to these variables.

Regarding mathematical skills, in Advanced Level physics teaching there seems to be an emphasis on the mathematical treatment of physics topics. Educators like Champagne *et al* (ibid.) claim that this emphasis is justified, since "mathematics is the medium of analysis and communication in the study of mechanics and that proficiency in mathematics provides the necessary and perhaps sufficient condition for success in learning physics". Others like McClelland (1985) argue that teachers tend to introduce topics in mechanics (which is the area

this research focuses on) in a limited and stereotyped way, and then rush to algebra. They probably take for granted that students have acquired the necessary understanding of concepts, models and theories. Sometimes knowledge of the mathematical background of physics (correct solution of equations, the ability of the student to categorise the problem under a limited number of possible recipe-like problems) is considered sufficient evidence of the understanding of scientific concepts.

Focusing on Newtonian mechanics' content preconceptions, there is also a discrepancy between the physical quantities' common meaning and their scientific one. Caillot (1992) points out that the definitions of quantities such as velocity, acceleration, force, are rather different in their common meaning. This means that when students learn mechanics, they have already developed models of phenomena which are inconsistent with Newtonian mechanics.

Furthermore, as several studies have shown (e.g. Viennot, 1985), students in secondary school or at a university level insist on their "velocity-Force reasoning": they often answer as if there were a direct relationship, between velocity and force or, as if motion (v) implied force (F). Students find it difficult to accept that "in Newton's abstract idealised and frictionless world the behaviour of objects is vastly different from their behaviour in the Aristotelian world and the central concept is the acceleration of objects not their velocity" (ibid.). Even after instruction in Newtonian mechanics has been given, some students who achieve a grasp of Newtonian mechanics theory still use their "naive" frameworks.

Practical work can potentially facilitate learning by making the physics formalisms relevant to the students by linking domain knowledge learnt in the classroom to relevant activities in the laboratory. However, several reasons why students retain their prior conceptions in spite of science practical work have also been identified (Tamir, 1991):

1. Lessons are perceived by students as isolated events, not as parts of a related series of experiences as intended by the teacher.
2. The students' perceived sense of task is different from that of the teacher's. The tendency therefore is for students to construct a purpose for a scientific classroom task either "following the set instructions" or "getting the right answer".
3. Students fail to understand the relationship between the purpose of the investigation and the design of the experiment which they carry out.
4. Students lack assumed prerequisite knowledge.
5. Students are unable to grasp the "mental set" required.
6. Finally, students' perceptions of the significance of task outcomes achieved are not those assumed by the teacher.

2.3. Computer assisted learning

Computers can transform the learner's educational experience by suggesting alternative ways of approaching learning tasks. They offer alternative or complementary experiences to the ones provided in the classroom. Borghi (1991) among others, makes the point that a computer can be a particularly effective tool for its graphic facilities and for the interactivity which allows students to observe animation on the screen, to modify their conditions of observation at leisure and

to evaluate quantities.

Educational software has been classified in a number of ways by researchers. A classification, which dealt with computers' possible uses (Scaife & Wellington, 1993) identified four paradigms by which students learn through the use of Information Technology:

- (1) Instructional (drill and practice)
- (2) Revelatory (simulation)
- (3) Conjectural (modelling)
- (4) Emancipatory (computer as a labour-saving device).

(1) and (4) represent aspects of the use of computers as a secondary learning tool, either as an instructional tool which provides information and opportunities to practice certain skills (e.g. answering revision questions, browsing through hypermedia-based information which complements a textbook) or used as labour-saving devices (e.g. drawing graphs, calculating fast). It is (2) and (3) though that offer a new approach to learning by using computers as tools for visualisation and modelling.

Another interesting classification of educational software is that by Wellington (1985), his criterion being a differentiation between teaching and learning programs.

Both classifications are characterised by an increase of learner control across their spectrum. In the first one (Scaife & Wellington, 1993), there is a move across paradigms (instructional, revelatory, conjectural, emancipatory) from "computer in control" ones, which are subject-centred and content-laden, to "student in control" ones,

which are learner-centred and content-free. Similarly in the second taxonomy of teaching and learning programs, the latter “tend to impose slightly less control on the user” than the former.

In physics education research there is a shift of focus mainly towards three possible uses of computers:

(1) on-line acquisition of data, which, according to Balzano *et al* (1992), potentially subverts many aspects of traditional learning of physics. In A level physics computers are quite often used as laboratory tools, (instructional and emancipatory paradigm). Hardware and software are designed to collect, display and analyse data. This type of use calculates or tabulates data, for statistical analysis or for drawing graphs. These tools enable experiments to be made in various areas of physics.

(2) simulation and modelling, through which reality is gradually “revealed” to the user, as she can investigate the “necessary relationships between physical concepts and mathematical representations, a crucial step in the appreciation of physics ability to interpret facts” (ibid.), as she “must be taught to examine and question models of reality” (Scaife & Wellington, 1993). The difference between modelling and simulation is that in the former the learner participates in the construction of a suitable model while in the latter she uses the model which has been implemented by a designer/programmer.

(3) virtual reality tools, which open new horizons for learning by going beyond the limits of the Direct Manipulation Interface.

Simulations belonging to the revelatory and conjectural paradigm, can change and “massage” students’ prior conceptions into the experts’

views. They can also complement and have an impact on laboratory work. Simulations will form the main part of the research described in this thesis, with an emphasis on their design and use in an instructional context.

2.4. Simulations

Computer-based simulations are interactive learning environments based on a model of a situation or an aspect of the world to be explored by students. The model is created by a designer/programmer, based on the underlying scientific theory and, according to Tao *et al* (1993), is often not made transparent to the students. As Laurillard (1992) points out, simulations enable the students to experience a version of the world directly and thereby formulate a better conceptual understanding of it.

In science, simulations represent natural phenomena which are formalised into a model of the natural phenomenon and implemented as a computer program. Students' learning centres around interacting with the simulation. They can investigate the underlying scientific model by asking questions and getting answers. They interact with the model by changing the conditions and variables and visualising immediately the consequences of such manipulation. In this way, according to Tao *et al* (1993), students can:

- investigate how the variables in the model are interrelated,
- make and test hypotheses about the model and
- interpret and reflect on the model and relate it to reality

In many cases simulations deal with a simplified and idealised

version of the natural phenomenon. Close correspondence between the simulation and the simulated is not necessary or even desirable (Brown, 1989). This is, according to Hennessy (1993), one of the pleasing properties of simulations (that they do not necessarily have to portray accurately a model of the world), since they can be used as a method of both monitoring a student's beliefs about the world, as well as provoking her into examining these beliefs.

Arguments in favour of the use of simulation-based learning have been described exhaustively by Wellington (1985) and Goodyear (1991):

- Simulations allow learners imaginative access to new areas of experience, through role-play and decision making.
- Simulations allow learners to control complex systems, manipulating variables, running experiments, taking measurements, etc., in ways which would be difficult or impossible to achieve with real world systems (i.e. in simulating a process which could not otherwise be shown because either the time scale is too long or too short, or in simulating processes which are either invisible, or theoretical, or a mixture of both).
- Simulations allow learners to understand the functioning of complex devices, which might be too expensive to work with, or too complicated to understand (saving money and time), through direct experience of the real equipment. Also for safety reasons, certain experiments may be too dangerous to carry out in a laboratory or a classroom.

But there are also arguments against the use of simulations. They are mostly related to the simulations being presented as a poor substitute for the real experiment. Research (Goodyear, 1991) has been

questioning the value of simulations as it is claimed that they are removed from the existential context of the human experience that they are intended to represent. He points out that “a computer-based simulation reduces rich, physical sensory experiences to cold, abstract visual analogies” and suggests (*ibid.*) that simulations mechanise experience.

Certainly there are difficulties in the effective use of simulations. Wellington (1985) and Goodyear (1991) outline some possible implications:

- The learner may lack the higher-level or domain-independent control, investigative or problem solving skills that sustain effective exploration of, or experimentation with, a simulation.
- The learner may have unhelpful beliefs about the nature and value of simulation-based learning: simulations may give rise to unwanted misconceptions about the way physical processes and natural phenomena work. For example pupils may be led to believe that variables are both easily controlled and independent of each other. In reality, not all variables can be as easily, as equally or as independently controlled as many simulations suggest.
- The learner may have inadequate domain knowledge. She may also not be able to relate the knowledge acquired, in working with the simulation, to the real world, or to cognate domains.
- The learner may run into a particular problem, which the support materials did not foresee, or the pragmatics of the learning situation may render the support materials inapplicable or unavailable.

Table 2.1 summarises the arguments in favour and against simulations. All the above points emphasise the importance of appropriate support when using computer-based teaching systems. Watson (1993) states that teachers and children engage in constructing a shared account, a common interpretative framework for curriculum knowledge.

| IN FAVOUR | AGAINST |
|--|---|
| Allow imaginative access to new experiences through role-play and decision making. | Reduce rich, physical sensory experiences to cold, abstract visual analogies. |
| Allow users to control complex systems, in ways which would be difficult or impossible with real systems. | Provide poor substitutes of the real experiment. |
| Allow users to understand functioning of complex devices, which might be too expensive or too complicated. | Mechanise experience as in reality, natural phenomena cannot be as easily controlled as many simulations suggest. |
| Help users to change prior conceptions. | May give rise to unwanted misconceptions about the way physical processes and natural phenomena work. |
| Certain experiments may be too dangerous or too expensive to carry out in a laboratory or a classroom. | Users can become lost in a sea of variables and data. |

Table 2.1. Arguments in favour and against simulations.

Most students, according to Lewis (1991), felt they needed personal contact with staff when they had questions arising beyond the feedback the computer offered. Certainly, as Watson (ibid.) also points out, worthwhileness of software is teacher dependent and this certainly applies to all interactive learning environments.

2.5. Microworlds and simulations

There is confusion in the use of the terms “microworld” and “simulation”, understandable, as Laurillard (1993) states, since it is a feature of simulations that they allow the user to act within a “little (micro) world”. She offers a comprehensive analysis of the similarities and differences: microworlds and simulations are similar in that they allow the user to act in a simulated world within the constraints of the designer. The difference is in the way the student interacts with a microworld: a mediating mechanism for acting in that world is provided (a programming language) with effect a symbolic representation of the student’s description of the events (the program statements).

This is certainly an interesting criterion for differentiating between a microworld and a simulation, but the existence or not of a programming language and a feedback mechanism, which supports the student’s description, is not a general enough criterion to assess the variety of forms a simulation can take. Simulations too can support the students’ description directly by offering them a multitude of options for decision making and control, and also give them the feeling they are active participants in the simulation’s world.

According to de Jong (1991), a microworld can be seen as an environment in which learners may exhibit exploratory behaviour within a set of well defined microworld boundaries. Originally these boundaries were not domain specific. The best known example of a microworld is LOGO (di Sessa, 1982). The confusion derives from the fact that the concept of microworlds is nowadays used for models of domains, thus creating a vague boundary between microworlds and simulations. In the rest of this thesis the term simulation will be used

to mean a microworld within a physics-based domain.

2.6. The use of simulations in an instructional context

Simulations can be used independently, simply substituting for an experiment or used in conjunction with practical work. In both cases it is common for the simulation to be a part of an instructional session, which may involve several phases, one of which is the interaction with the actual simulation.

2.6.1. Simulations and practical work

According to Kahn (1985) activity in the science laboratory is structured in both space and time: the laboratory is subdivided into areas with different functions, and students learn what behaviour is appropriate in which areas:

Laboratory tasks are organised through time and require a sequence of operations. Many tasks involve teams of students and these teams are further subdivided, informally or formally, when individuals choose or are allocated different roles. Yet behind all this structured activity is something very abstract: the scientific model which is being tested by experiment.

(Kahn, 1985, p50)

Tamir (1991) gives a taxonomy of aims and objectives for practical science. These are:

- i. understanding concepts
- ii. acquiring habits and capacities
- iii. gaining skills (planning and designing, performance, organisation,

analysis, interpretation of data, application to new situations)

iv. appreciation of the nature of science

v. developing attitudes

However, learning in the laboratory is a complicated procedure. It can be difficult for a teacher to help students master the topic through laboratory experiments. There are cases where the necessary experimental set up would have to be so complex and so great in size (scale of the experiment) that it could not be prepared (Borghini, 1991), when invisible or theoretical processes might take place, when the experiment might be dangerous to explore in the classroom (Wellington, 1985), or finally when the experiment would take too long.

Practical science can achieve its objectives in combination with computer simulations, designed to involve students in inspiring activities. Even when used independently a simulation is not merely a substitute for some experimental activity. Computer simulations are often able to do things that experiments cannot, as Kahn (1985) points out, while still involving the same process of scientific model testing used in actual laboratory experiments. For instance, there are several models, which are based on many experiments done over many years in different laboratories and no single experiment can demonstrate the entire range to students.

A computer simulation can either be completely stand alone or can be made part of a laboratory session which involves several activities, some of which are practical laboratory experiments.

2.6.2. Simulations as part of a teaching/learning cycle

An interesting instructional approach for the use of simulations consists of multiple-phase cycles, which may involve several phases, one of which is the interaction with the actual simulation. A computer simulation can be made part of an interactive session in the classroom. This instructional approach has been used by White (1992), by Tao (1993) and Lunetta & Holfstein (1991). Though not exactly identical, these cycles follow similar patterns:

- (1) the **motivation** or planning and design phase, where the students formulate questions and hypotheses to be tested and are asked to make predictions about the behaviour of real world objects. Since these questions relate to real world objects, as White (ibid.) points out, they create the potential for linking what happens in the simulation with what happens in real world situations.
- (2) the **evolution** or performance phase, where students manipulate materials, make decisions about investigative techniques, observe and record data. In White's (1992) cycle this means specifically that they go to the simulation, and attempt to solve a series of problems. These activities are designed to help students induce the laws of the simulation for themselves.
- (3) the **normalisation** or analysis phase, where the students process data in various ways and search for generalisations. They work at their computers, using for predictions a number of possible laws which describe the behaviour of the simulation, finally agreeing on the best laws they have.
- (4) the **transfer** or application phase, where students' behaviours go beyond the results of the particular investigation. They must

apply the laws of the simulation to real world situations. The aim is to make the students see the relationship between the simulation and the behaviour of the objects in the real world.

2.7. Taxonomy of science simulations

A number of taxonomies of simulations have been made by research using such diverse criteria as the type of data involved in the interaction, domain, level of learner or considerations of attributes of a simulation. Taxonomies are useful in that they highlight similarities and differences and put an emphasis on significant simulation attributes.

Simulations can be categorised according to the kind of data (dynamic or static) involved in the interaction. Dynamic data are collected by the users, when they interact with the simulation, and are examined to detect similarities, while static data have been collected in earlier scientific studies but are similarly examined by the users for similarities. Thus, simulations appear to belong to two major categories (Table 2.2).

The first category (**equation driven simulations, dynamic data**) is related to mathematical equations which, when stored in computer software, can model a scientific system. The students can also examine graphs and derive relations between variables from these.

| TAXONOMY OF SIMULATIONS | | | | |
|-------------------------|-------------------------|------------------|--------------|------------------------|
| 1 | Equation driven | | Dynamic data | |
| | Data driven | | Static Data | |
| 2 | Aspects of a simulation | | | |
| | Interface | Underlying model | Motivation | Reality representation |

Table 2.2. Two taxonomy of simulations (Hatzipanagos, 1995).

A drawback of this type of simulation, as Lunetta & Hofstein (1991) point out, is that students can become lost in a sea of variables and data, as happens to many laboratory activities, if they do not receive assistance in controlling variables and in sharpening hypotheses and investigative techniques.

The second category (**data driven**) deals with static data: some simulations present or allow access to data collected by others, either directly inspecting data or indirectly examining a visual or graphical representation of the collected data. With this kind of simulation, users can interrogate the database and search for regularities and order. In the process they can acquire new information, improve their conceptual understanding, and develop skills in analysing data. Laurillard (1994) expresses doubts about the educational value of the second category as interactive software, because the program runs without any input from the users who simply watch. However, there are data driven simulations (like Multimedia Motion which is described in 2.8.5) which use the computer’s interactive, graphic facilities and involve the user in taking an active role in data collection and decision making.

| TAXONOMIES OF SIMULATIONS | | | | | |
|---------------------------|-----------------------------|------------------|---------------|----------------------|-----------------|
| | De Hoog <i>et al</i> (1991) | | | Domain driven | |
| | | | | Learner-level driven | |
| | Physical sims | Underlying Model | Presentations | User Actions | System Feedback |
| | Alessi (1988) | • | • | | |

Table 2.3. Taxonomies of simulations.

De Hoog *et al* (1991) suggests another type of taxonomy (Table 2.3) in which simulations can be classified according to their domain and the learners' level, and asks how this will affect the simulations' design: "Is the effectiveness of the model's representation learner-dependent, i.e. for the same domain, should the novice learner be presented with a different interface than the one the expert user interacts with?" The implications of such a question are discussed in the next sections as an introduction to the issue of representation in simulations, which is central to this research.

Alessi (1988) offers a categorisation of simulations according to domain, as physical, process, procedural and situational. Four aspects of simulations are important to all these categories (Table 2.3): Underlying Model, Presentations, User Actions and System Feedback. **Underlying Model** represents the rules underlying the simulation's physical object. For **Presentations**, primary considerations are the visual and audible stimuli and the time frame in which events occur. **User Actions** represent the number and type of actions the student may engage in. For **System Feedback** considerations include whether there is any feedback, whether it is immediate or delayed, and whether it is realistic or artificial.

Underlying Model and Presentations are more important for the design of physical simulations (which are relevant to this research), since the instructional objectives concern learning about the phenomenon and the theory underlying it, (which is represented by the Underlying model), and the visual stimuli (Presentations).

For the purposes of this research a framework was used in the literature review for classifying physics simulations which comprised four factors: underlying model, interface, motivation and representation of reality (Hatzipanagos, 1995). This framework was derived from the taxonomies described in this section:

- The distinction between equation driven and data driven simulations was considered as useful, since one of the reviewed simulations in 2.8 is Multimedia Motion, a data driven simulation, not a common occurrence since most simulations are equation driven.
- The domain is important since the nature of physics simulations impose particular considerations in their design for representation of physical knowledge. These are mainly an emphasis on representation of physical knowledge and the use of complementary, multiple representations of the simulation data to convey necessary information to the user.
- The learner level is also important though educational software is quite often task dependent. A designer's consideration should take into account the level of the user (novice or advanced).
- Reality representation is relevant, as a measure of how the look and feel of a simulation compares to reality. Each of the categories of this taxonomy is discussed in the following sections.

2.7.1. Underlying model

Every physics simulation is based on a model of reality, whose mathematical expression is the model underlying the simulation. The designer/programmer provides this model which is usually hidden from the users and cannot be altered by them. The model consists of mathematical equations. What the users can do is manipulate the variables, observe the effect of their choices and find out how the variables are interrelated. Their observations can lead them to discovery learning (Scaife & Wellington, 1993). By understanding the model they can compare it and relate it to the real world.

2.7.2. Visual representation and interface

Shneiderman (1987) suggests that research on problem solving and learning shows the positive influence of visualisation on the learning process, in comparison with textual and numerical representation. An important property of simulations is that they help the learner to visualise the simulated phenomenon. This visualisation can be aided by the use of textual and numerical data representations.

A significant related question concerns the representation of the underlying model: "How can the model be represented to the learner?". De Hoog *et al* (1991) consider two basic properties of the system which should facilitate the learners' understanding:

- (a) the representation should allow the learner to have a "view" (or a number of views) of the model, in order to get an understanding of it, since it is the function of the learner interface "to permit a transparent view of the model".
- (b) the interface should permit the learner to manipulate the model (learner

activity).

(De Hoog *et al*, 1991, p365)

The interface is the medium between the simulation and the simulated (modelled system) through which the user can operate in the simulation. As Hazari & Reaves (1994) point out the most important consideration in interface design is how well it simplifies access to the program, how “natural” or “intuitive” it makes computer use.

The interface presents realistic or abstract aspects of the real world to the user. In most cases it should become transparent and no longer exist for the user, so that the represented world becomes cognitively directly present. This is the notion of Direct Manipulation which was first used by Shneiderman (1987).

The use of graphic abstractions in the interface has a number of practical advantages for making models of physical systems inspectable. These advantages according to Wenger (1987) are:

- (1) there is no opaque material, components are not distributed spatially, and parameters can be displayed even though no actual instrumentation exists, and
- (2) the student can even become aware of transient phenomena by stopping the simulation or by single-stepping through procedures to gain a detailed understanding of their effects on the system.

2.7.3. Motivation

Research has explored the cognitive obstacles that stand in the way of

learning. Researchers like Czikszentmihalyi (1990) support the view that these obstacles are primarily motivational, not cognitive in nature. He refers to inadequate motivation in learners caused by a lack of balance between skills and challenges, a lack of clarity of goals and a lack of immediate feedback. Simulations have the potential to increase motivation in physics learners.

Watson (1993) makes the point that simulations enable students to become involved in more complex and challenging learning situations than normal. Challenge can be defined as a stimulus that attracts our attention and demands some response on our part (Czikszentmihalyi, 1990). In this sense challenging is related to intrinsic motivation which is a degree of how the simulation attracts the user's attention, that is, how it attempts to engage the user in the simulated world. The criteria for what exactly makes a simulation motivational can be subjective, e.g. how appealing the prospect of engaging in an interaction with the simulation might appear to the user (related to this is Malone's (1981) categorisation of the characteristics that make instructional environments interesting: challenge, fantasy, curiosity). A set of criteria for enhancing motivation in simulation users would deal with the following:

- (a) software which is self-explanatory, so that students will not have to spend a large amount of time learning to use it, which is non threatening and friendly even for first-time users, and which encourages underprepared and anxious students (Thornton, 1992).
- (b) discovery-based software where the students are allowed to "proceed at their own pace" and "choose their own path through material" (Scaife & Wellington, 1993).
- (c) Related to (b), is how much control of their learning the

simulation allows the students. By taking an active role, students are encouraged to construct physical knowledge from actual observation (Thornton, 1992).

(a) and (b) could refer to software in general, not just to simulations. Scaife & Wellington (1993) refer to the use of rewards and reinforcement as being motivational, if used carefully and thoughtfully. According to them (1993) there is a feeling, though with little evidence to support it, that computer simulations motivate students in science and technology education more than traditional practical work. Watson (1993) also claims that simulations were found to be good motivators which heighten students' interest and enjoyment and enable students to develop a high degree of empathy with the topic under study.

A significant link exists between the interface design and motivation since an intuitive interface can motivate students. The use of real time might also affect motivation, since students get immediate feedback when graphs are plotted in real time.

2.7.4. Representation of reality

Another important issue is to what degree a simulation is representative of reality, that is the way it attempts to be a successful "imitation" (not necessarily a copy) of the real system. A well designed, intuitive interface will contribute to the student's transfer of learning. Transfer of learning, as Alessi (1988) defines it, refers to a student being able to apply what is learned during instruction to a new situation, usually the intended real performance. This could mean

transfer to an actual practical demonstration as well as to a written problem.

It is accepted that simulations run the risk of providing “caricatures of reality” rather than representations of it, either because they are an idealisation of reality ignoring certain features in order to concentrate on others, or because they can be deceptive, misleading or inaccurate (Scaife and Wellington, 1993). Especially in mechanics, “real life” motions, as Caillot (1992) points out, are more complex than those studied in class, because bodies are not point masses and friction is always present (solid or air friction). Furthermore double idealisations can aggravate the problem: e.g. a simulation which uses a computer model of a scientific model or scientific theory which itself is an idealisation of reality (Scaife and Wellington, 1993). Representation of reality has to do with how similar the learning experience with the simulation is to a learning experience in the laboratory.

2.8. Review of simulations

In this section five simulations will be reviewed. The framework for reviewing them consists of the interface, underlying model, motivation and representation of reality. Puckland, Gravitas, Friction Worlds, Direct Manipulation of Mechanical Microworlds and Multimedia Motion represent aspects of how the design of a computer simulation could be dealt with. The aim is to describe their features in terms of the above categories and consider how useful the above taxonomy is for classifying computer simulations.

2.8.1. Puckland

Puckland was written in Hypercard for use with the Apple Macintosh (Whitelock *et al* 1991; 1993b; 1993c). The program simulates the physical phenomenon of the collision of two masses.

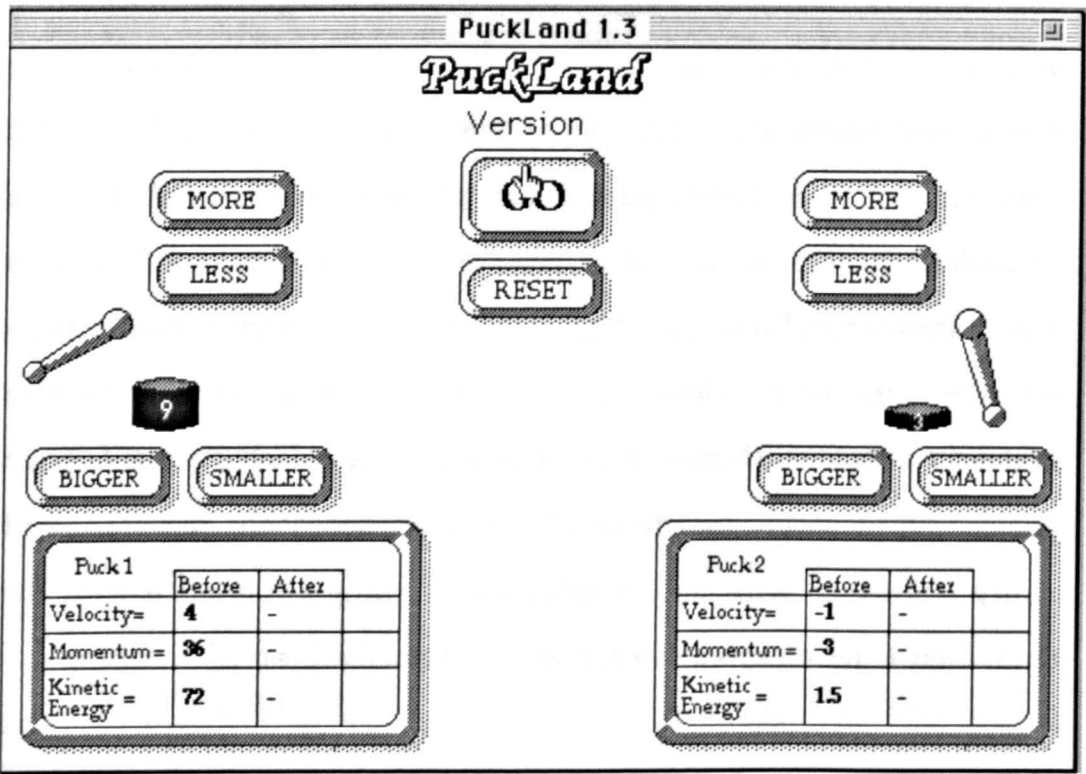


Fig 2.1. Puckland.

The simulation consists of a pair of pinball-style flippers on either side of the screen with which students can flick pucks (Fig. 2.1). The amount of force with which the flippers hit the pucks and the mass of the pucks can be varied. The variables are controlled by buttons which the user presses with the mouse. The buttons hide Hypertalk scenarios which determine the values of the variables used. When the GO button is activated the pucks move towards each other on the screen. The animation shows the two masses moving with speeds proportional to those set by the button presses.

After the pucks collide, they move in directions and speeds which are calculated from the correct physics formalisms. The principles of conservation of momentum and kinetic energy which govern the collision of the masses are obeyed. After the collision the screen velocities of the pucks are once again proportional to their calculated values.

At the bottom of the screen there is a grid which provides numerical information about the amount of energy and momentum that the system has initially, and then, subsequent to being run, the effect of the collision on these two factors. Every experiment attempted by users of the simulation is automatically logged by the computer.

Of the five simulations, Puckland is the simplest. The system enables students to observe the effects of values of variables on animated visuals which are basic but represent a 3-dimensional reality. An advantage of this simplicity is that students cannot be lost in a big number of variables. Puckland uses a direct manipulation approach to allow students to investigate the interaction between the two ice pucks. The interface is enhanced by numerical representation of the users' choices, but there is no graphical representation of the physical quantities, which would function as a visual aid to the students.

Puckland reveals to the students the principle of conservation of energy, which they derive from the quantitative data given after every collision. It allows students time to run experiments which they think confirm their faulty models, but in practice it facilitates an understanding of the principle of energy conservation (Whitelock *et*

al, 1993b). Its underlying model is simple (the only variables are the masses of the pucks and their velocities).

However, even though Puckland is simple to use, it could be argued that its intentional design simplicity does not provide a very challenging environment in terms of intrinsic motivation.

Finally, it can be considered realistic in terms of the animation effects and the behaviour of the ice-pucks, so users can accept that it represents a scientific model like the ones demonstrated by suitable physical apparatus in the science lab.

2.8.2. Gravitas

Gravitas is an interactive system which runs concurrently with a Logo interpreter on a Macintosh II computer. It is a discovery learning environment which allows learners to build systems of gravitating objects (Sellman, 1991; 1992; 1994). Gravitas can give students an idea of the gravitational forces on real (the moon, the earth, etc.) or imaginary systems and their effect on the motion of masses, which would be difficult to understand through direct experience.

The objects in Gravitas are called MassObs-simulations of real objects with mass, position and velocity. They are dynamic objects which move continuously across the screen at their current velocity while the system keeps track of the elapsed time (Fig. 2.2). Each MassOb is affected by the gravitational pull of every other. The system has two distinctive interfaces: the first is graphical and allows the system to be driven by the mouse; the second, the linguistic interface, is an extension of the programming language Logo. Gravitas' window has

two sections. At the top is a square black region representing space, into which the user may place MassObs. At the bottom of the window there is the graphical interface. The push button controls allow the dimensions of the space and the physical properties of individual MassObs to be given values. The graphical interface also lists all the currently defined MassObs and allows users to create new ones. The simulation allows students to investigate the dynamics of Newtonian gravitating masses which can be created by the user.

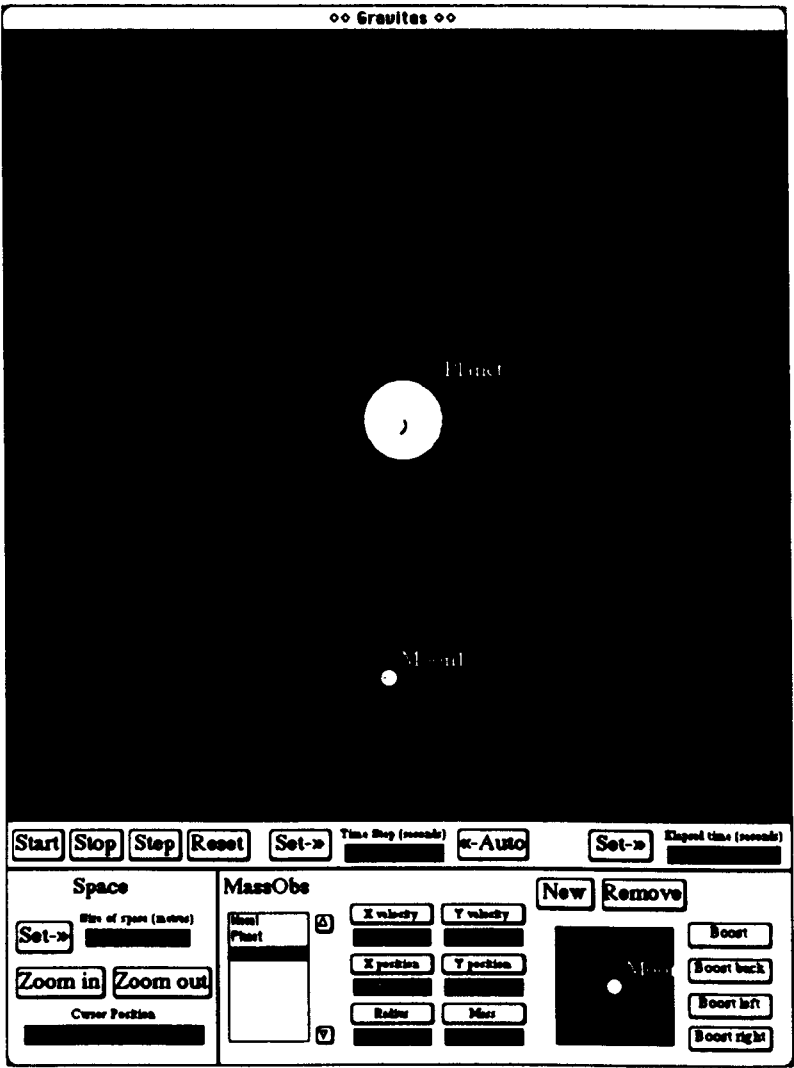


Fig 2.2. Gravitas.

Gravitas does not have a completely Direct Manipulation interface

(not all the items of interest can be set by direct actions of the mouse), though the advantage of having a semi-Direct Manipulation interface is, according to Sellman (1994), that the user can set variable quantities with more precision, since MassObs can range over many orders of magnitude. Its relative simplicity is undermined however by inconsistencies: lack of physical analogies in a number of cases and the lack of explanations concerning these inconsistencies. The interface, through which the user supplies inputs and observes results and can derive relations between the variables, could be described as abstract and 2-dimensional, though with a few visual aids in the form of counters and numerical representations of the variables involved (no graphs are included). The combination of graphical and linguistic interfaces may have implications in the students' accepting the simulation as representing aspects of the real world.

Gravitas consists of a mathematical model of the real system, which provides the parameters of the model. This mathematical model is quite a complex one, i.e. variables have a bigger range than Puckland (the user can select an infinite number of MassObs and variables in the x and y dimension, which give Gravitas an increased sophistication). It provides a wide variety of possible combinations for the students to attempt to explain and test their theories on.

Gravitas does not provide a user friendly, self-explanatory environment and it certainly is rather complicated, at least for first-time users, because of its linguistic interface. However the behaviour of the MassObs conforms realistically to the behaviour of planets, rockets, satellites etc.

2.8.3. Friction Worlds

Friction Worlds was implemented in Hypercard 2.0 by Spensley for use with the Apple Macintosh. The use of the software enables students to observe the effects of different values of variables on animated objects, depicting the motion of the masses. The simulation allows them to investigate the horizontal motion of blocks of various masses and surface areas (Hennessy *et al*, 1989; Spensley *et al*, 1990).

Friction Worlds concerns the effects of sliding friction on the motion of these blocks. The blocks are dropped down a chute and across one of three surfaces with different coefficients of friction (Fig. 2.3). Students observe their behaviour. On the screen are three hoppers containing ice, sand and syrup which can be made to deposit a quantity of their contents onto a bounded surface below. As a block falls, the various meters record the height from which it was dropped, the time it took to fall, the velocity with which it fell down the chute, and the horizontal distance travelled. It also presents students with seven "alternate realities" (Smith, 1987). These are presented as different planets. The behaviour of the blocks on these planets is determined by varying the effects of surface area and mass on the horizontal distance travelled. The students' task is to identify on which of the planets the blocks' behaviour corresponds to that of the real world.

In Friction Worlds all the operations on the interface involve using the mouse only (clicking buttons and dragging objects). It is simpler in relation to similar experiments taking place in the lab because it uses a number of idealisations:

- (a) frictionless chute

(b) no air resistance

(c) idealisations about the nature of the materials of the surfaces (sand surface like sand paper, non-sticky syrup).

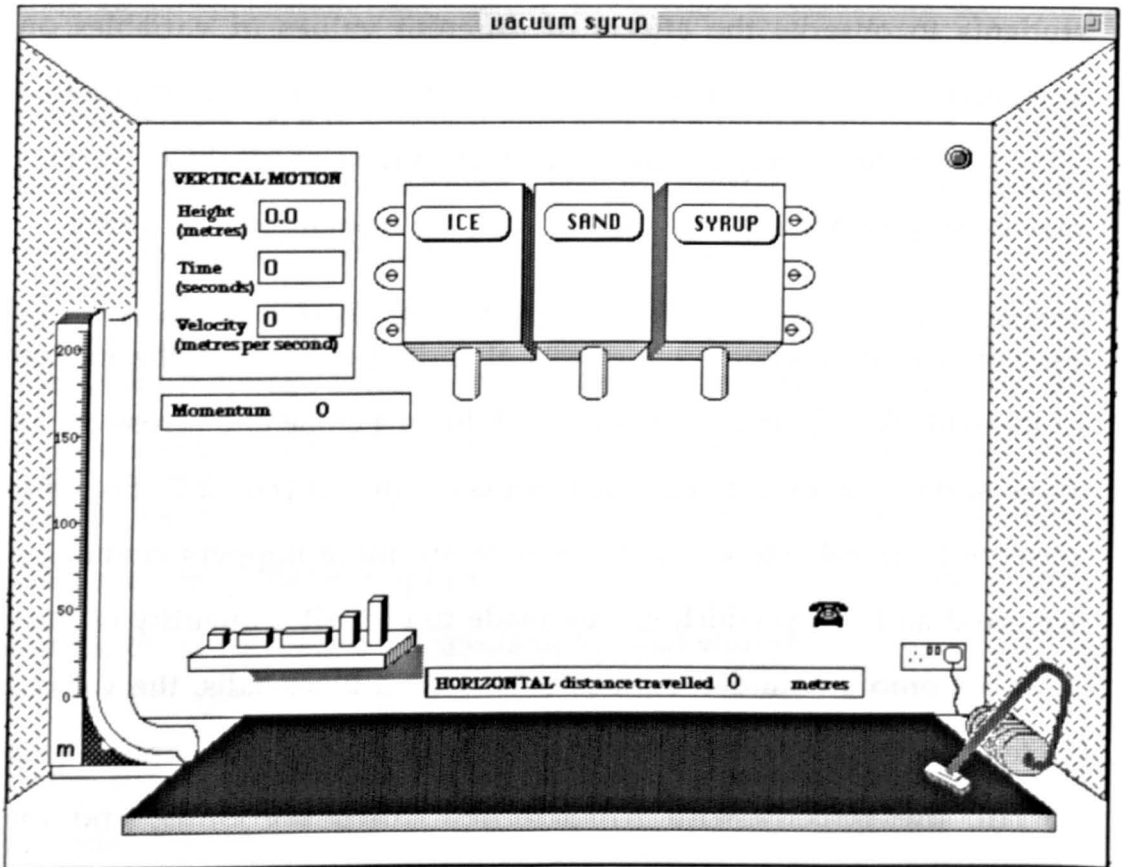


Fig 2.3. Friction Worlds.

The interface is quite sophisticated, in terms of the graphics involved. However, though Hennessy (1989) claims that it proved to be transparent and realistic, requiring minimal explanation to learn, it could be argued that some explanations about the idealisations used (curved part of the chute mechanism, nature of materials on the surface where the motion takes place) should be necessary, since the interface might confuse the students if they used the simulation without assistance.

In Friction Worlds, mathematical equations related to horizontal

motion (acceleration, speed and distance travelled) model a scientific system. The students can derive relations between the variables and predict and explain which of the models (planets) corresponds to the real world. This underlying model is a relatively simple equation driven one.

It can be considered to be realistic in terms of animation effects and the behaviour of the moving blocks, though there are issues (nature of surfaces e.g. stickiness and liquidity of syrup, lack of gravity everywhere on the screen except in the chute, disappearance of blocks) which might cause problems to the users in accepting that it represents a scientific model similar to a physical apparatus in the science lab. Also the different realities were given names of planets with the risk of confusing the students about what the alternate realities of the planets represent: the behaviour of the blocks on the respective planets of our solar system or just alternate realities resulting from varying the effects of surface area and mass on the horizontal distance travelled.

Friction Worlds is a user-friendly, though not completely self-explanatory, learning environment, which attempts to challenge the users to think about the effect of friction on horizontal motion and thus improve their conceptual understanding. The illusion of three dimensions in the interface and the situations involved have the potential to motivate.

2.8.4. DM³ scenarios

DM³ (Direct Manipulation of Mechanical Microworlds) is an

interactive simulation building system. It was implemented in Smalltalk and allows construction of science scenarios, linking to everyday contexts. It simulates motion under forces, allowing students to observe the behaviour of objects in motion (Draper, 1991; Draper, 1992; Twigger, 1991). Four scenarios (cardboard box, rocket skater, speedboat, and parachutist) were developed, following an analysis of learners' conceptions and an analysis of the physics domain. Each of them is related to situations and the physical laws active in them and to particular aspects of students' prior conceptions. The four scenarios are (Twigger, 1991):

- (1) Horizontal motion with friction: the scenario depicts a person pushing a box (a) on a smooth floor in a supermarket; and (b) on a rougher surface in a car park. The size of the push can be controlled and the subsequent motion can be observed.
- (2) Horizontal motion with negligible friction: this scenario depicts a powered ice skater moving in one dimension. Forward and backward firing rockets can be fired. Motions of a "thin" and "fat" skater can also be compared.
- (3) Horizontal motion with speed-dependent resistance: this scenario features a speedboat. The throttle of the boat is under the user's control. As the boat speeds up the fluid resistance increases and a terminal velocity is reached (Fig 2.4).
- (4) Vertical motion under gravity: the scenario depicts a parachutist leaving a helicopter and falling to the ground. The parachute can be opened at any point in the fall and the motion with and without the parachute can be compared. A "thin" and a "fat" parachutist can also be used and their motions compared.

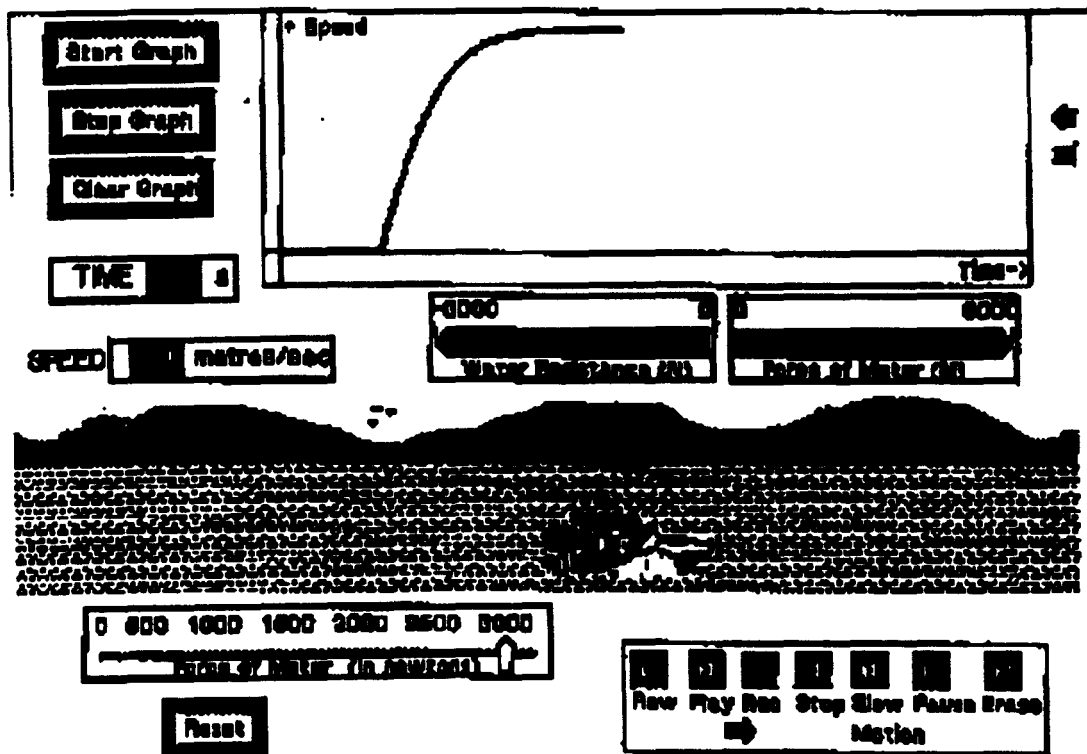


Fig 2.4. DM³.

At each time-step in the simulation each force is examined in turn, and each object subject to that force is noted. Then each object sums the forces acting on it, and calculates its own acceleration, its new velocity, and new position. Next each object that has moved has its screen image updated (Draper, 1992).

The DM³ scenarios correspond to a series of intuitive interfaces. Animation effects are combined with a direct manipulation interface where users are given control over the objects and forces via mouse-activated controls such as buttons and sliders. They can observe both the results of their actions as simulated motion, the counters on the screen and the speed-time graph. The graphing facility draws the graph of some quantity against time. A simulated video tape recorder facility is also provided so that users can record and replay a sequence in the simulation. The direct manipulation interface can give the users the feeling that they are directly manipulating the objects

through the icons depicted on the display screen (Draper, 1992).

The four DM³-based scenarios allow students to investigate and identify simple relationships between variables in the environment of the simulation. The underlying model is based on physical variables and the equations that connect these variables. They provide an interactive learning environment where students using discovery-based software “play” with icons of familiar real life objects. Research on its use has shown (Draper, 1992) that it is intuitive and easy to learn.

Finally, the DM³ scenarios are realistic in terms of convincing representation and animation effects. One could probably argue that a more uniform structure of the interface would enable the students to have a homogeneous idea about the simulations as instances of the same physics laws, but the simulation engine gives the teacher the freedom to create lessons (scenarios) adjusted to the students' needs.

2.8.5. Multimedia Motion

Multimedia Motion (MM) is a series of sequences of a CD-ROM based interactive learning environment. They were designed by Graham and Glover. MM is a data driven simulation which deals with static data, as it involves the user in collecting data, without having any choice over the values of variables. However the simulation does not run without any input from the users. MM is based on a combination of video and Newtonian treatment of the underlying physics model. The users can watch Quick Time¹ movies from a video source, where

¹ In its simplest form, QuickTime is software that allows users to play and edit digital video, as well as other types of media on a computer.

each sequence can be played repeatedly through as a movie. Then they can collect data by watching the simulation frame by frame and clicking on the screen. The pattern of the clicks is visible on the screen as overlaid points.

Thus MM allows the user to take calibrated measurements from screen observations. The movie option is helpful in previewing the measuring stage, allowing the user to decide which objects to track (Fig. 2.5). Data can be saved in formats suitable for importing into spreadsheets. At the end of the sequence, the user can examine these spreadsheets of the collected data and graphs of position, velocity and acceleration against time. The idea is that the user can compare the graphs to the spreadsheets and the frame by frame sequence and make connections. Connections can be drawn between events such as initial impact and the corresponding sharp changes on the graphs. There is also a text and voice commentary, both providing the same summary connections with relevant dynamics theory.

Multimedia Motion has a sophisticated interface, with a movie function which relates the physics laws to realistic representations of the real world. The novelty in relation to the previous simulations is also the use of colour in the interface. The interface also provides numerical and graphical representations of the collected data.

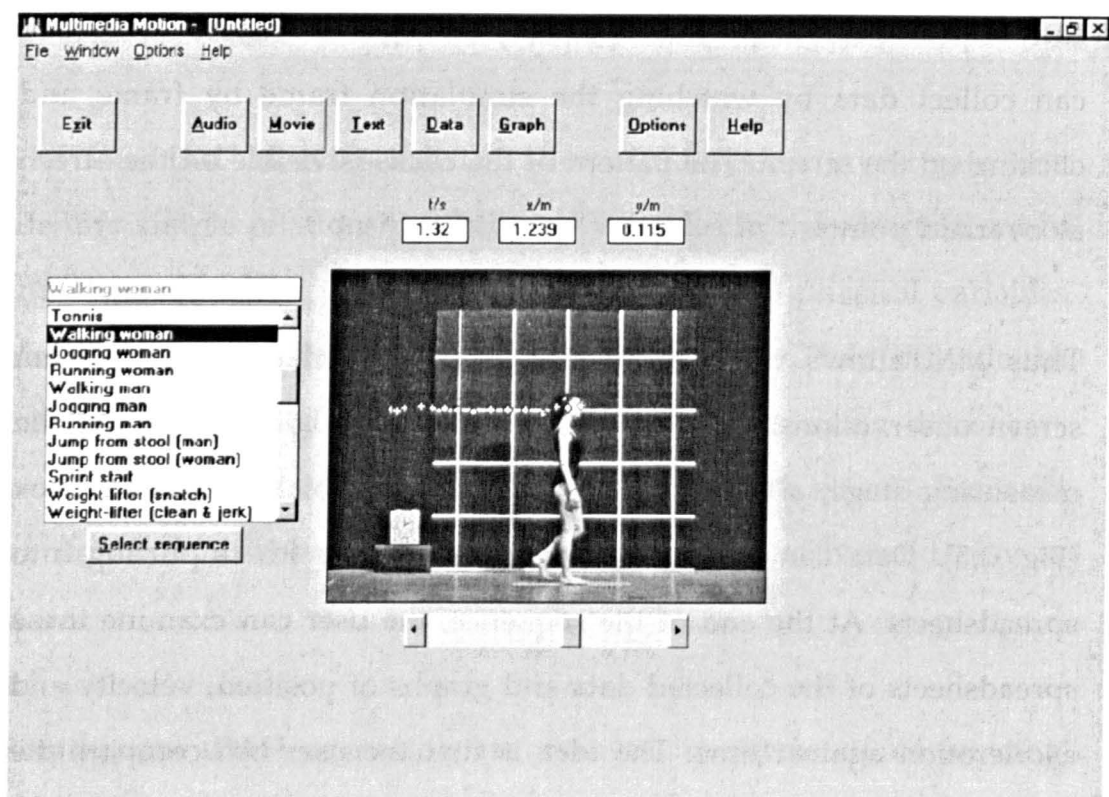


Fig 2.5. Multimedia Motion: interface.

Behind the MM sequences' visual sophistication are data represented by points on the screen which correspond to relatively simple Newtonian underlying models whose complexity certainly depends on the simulated phenomenon (e.g. the linear collision sequence comprises 4 variables, masses and velocities of colliding objects).

Certainly the use of the video clips, Quick Time movies and colour can enhance students' motivation or interest. This also gives the user the illusion of operating within the system itself by demonstrating animated objects with realistic behaviour like the ones in the science lab.

2.9. Conclusion

In the beginning of this chapter difficulties with physics teaching were outlined. The emphasis was on mechanics where the interest of this research lies, since probably more than anywhere else in physics it is here where students' beliefs “parallel the descriptive aspects of Aristotelian physics in contrast to the formal Newtonian system of mechanics” (Champagne *et al*, 1980).

This was followed by a review of computer assisted learning focusing on simulations. Microcomputers, as Caillot (1992) points out, can help students to learn the concepts of mechanics better, to use their knowledge for analysing complex situations like those found in everyday life and to confront their personal representations with scientific models.

Results (Champagne *et al*, 1980; Spensley *et al*, 1990; Draper *et al*, 1992) indicate that carrying out simulated experiments in fictitious worlds, in which the laws of physics can be modified, helps students in differentiating between their individual frameworks and the formalisms of Newtonian physics. Such interactions through computer simulations might result in what Champagne *et al* (1980) calls “the student's private Newtonian revolution”, since many educators compare the reluctance of scientists to initiate a revolutionary reconceptualization to the reluctance of physics students to change their beliefs about motion.

The issue of how well simulations fit into an instructional cycle (White's 1992, Tao's, 1993, etc. instructional approaches were

described) was considered. Next, a comparison of five simulations was made. Four of the reviewed simulations were equation driven (equations which are stored in computer software and can model a scientific system), which is the predominant model in physics simulations, and one was data driven (allows access to collected data indirectly examining a visual or graphical representation). The taxonomy used considered four variables for comparing the simulations: **interface** as the medium between the learner and the scientific model, **underlying model** which the learners have to explore, **motivation** as a set of criteria for making simulations appealing to the learner and **representation of reality** as a measure of how experience compares with what the simulation complements or substitutes.

The above four variables proved to be useful in describing aspects of the simulations. The interface links external representations with numerical and graphical representations of the underlying model. Using this interface the users can manipulate the model's variables and find out how these variables are interrelated. The motivation issue is equally important as it evaluates simulations whether they are self-explanatory and discovery-based, non threatening for first-time users and if they allow user control. Finally representation of reality compares the learning experience with the simulation to a learning experience in the real world.

As the above issues needed empirical attention, in Chapter Three a pilot study was undertaken to investigate aspects of this taxonomy and the role they play in people's interaction with simulations. Two case studies with users interacting with Gravitas and Multimedia Motion

and their findings are described in detail. The studies tested the hypothesis that two variables from the above taxonomy, the interface and the underlying model are potentially useful factors in categorising computer simulations.

Chapter Three

Pilot Study

3.1. Introduction

The issues raised in Chapter Two, such as the use of appropriate frameworks for classifying simulations, and the use of simulations in instructional cycles needed empirical attention. Therefore, a pilot study was undertaken to explore the impact of the interface and the underlying model as factors in people's interaction with simulations. Motivation and representation of reality were also investigated as secondary but influential factors for the purposes of this research.

This chapter describes observations with learners using two computer simulations. Both are representations of physical phenomena. Gravitas uses physics idealisations to describe the physical reality of gravitational motion in space, while Multimedia Motion's interface consists of visually faithful video sequences of objects in motion. Both Gravitas and Multimedia Motion were described in detail in Chapter Two (2.8.2 and 2.8.5).

A description of the structure of the study (participants and aims) is followed by an outline of the procedure. Video taped sessions with participants and the analysis of the questionnaires are then described. Finally, the findings and their implications for this thesis are given.

3.2. Aim of the study

The aim of this study was to carry out a preliminary investigation on the use of simulations and to identify factors which contribute to their successful use by learners. There was no intention at this stage to measure cognitive changes in the users. An issue of interest was the frequency with which the interface and the underlying model was mentioned either directly or indirectly, during the interaction with the simulations. The observations were designed to lead to an understanding of these features' contribution to the user's construction of physical knowledge from observing the simulation and manipulating its variables. The study investigated a hypothesis that the interface and the underlying model are potentially useful factors in categorising computer simulations.

3.3. Participants

Nine participants took part in this pilot study: five A level students from a school in the Milton Keynes area (the participants in the Multimedia study), three research students and a university lecturer (the participants in the Gravitas study). All users had a background in physics either by doing, or having done A level physics in school and/or having studied physics at University level (graduate and postgraduate level). All the A level students were considered to be novices (they had been recently taught at school the physics content of the simulation but did not have the expertise/background in physics to be considered experts. The participants who had graduate or postgraduate level of physics knowledge were classified for the purposes of this research as experts.

Participants had previous experience with computers, and using a mouse as an interface device, though two of them had not used a Macintosh computer before. Their computer skills ranged from word-processing, spreadsheets and databases to programming. All of the users knew what a computer simulation was and the majority had previous experience of using computer simulations, as Table 3.1 shows:

| | |
|--|----------|
| I have used a computer simulation before | 7 or 78% |
| I have never used a computer simulation | 2 or 22% |

Table 3.1. Previous knowledge of simulations.

Participants worked either individually (Gravitas) or collaboratively (Multimedia Motion), as shown in Table 3.2. The pairing of the ones who took part in the study collaboratively was decided on the basis of availability when the study was taking place.

| | |
|-------------------|------------------------|
| Gravitas | 4 (individuals) |
| Multimedia Motion | 5 (1 triad and 1 pair) |

Table 3.2. Users in the pilot study.

The group certainly had a non homogeneous structure, consisting of experts and novices. Gravitas was felt to be more suitable for users with more background in physics, while Multimedia Motion was used with novices. Furthermore a secondary aim was to compare the experts' and the novices' attitude to the simulation.

3.3. Procedure

Each session typically lasted two hours. The participants were taken to a room where a Macintosh computer (for Gravitas) or a PC (for Multimedia Motion) was set up. The computer was controlled by a mouse and a keyboard. The participants worked at the computer observed by the researcher. All the users were videotaped. A video camera was used to record the interaction. The camera was positioned on the screen. The outcome was a recording of the computer screen with an audio recording of the participants' discussions while they were using the simulation. An observation schedule of the interaction was also kept.

3.4. Description of the questionnaires

The users completed pre and post test questionnaires. The questionnaires consisted of :

- questions on participants' experience on computers, science and simulations.
- questions on whether the users had any perception of the usefulness of simulations
- questions on their knowledge of the physics context of the simulations
- their opinion about their performance after the interaction with the simulation.

- their opinion about the simulation (interface, slow or quick response to their choices) and whether the simulation helped them to understand better the simulated phenomenon.

A prior concern was that the simulations should be used in an effective way, not simply following the “ritual” of creating conflicts with the users' prior conceptions and then giving them the scientific explanation. Two different approaches were tried.

In Gravitas, the instructional approach followed the pattern “*predict-observe-explain*” often used with simulations (Gunstone, 1988). The purpose of this pattern is to recognise when a conflict has arisen. In this kind of approach the user is told of some demonstration (in this case the simulated phenomenon), which will be performed, and asked to predict what will happen. The demonstration is performed (in this case the user runs the simulation), and the observation made by the user is probed. The reasons for which the student made the specific predictions are explored. In the end the student is asked to repeat the initial prediction.

The users interacted with Gravitas individually and they were asked at crucial points of the interaction, while constructing the gravitational system and before running it, to make predictions on the behaviour of the system. An effort was made to ensure that both the questionnaires and the tasks to be performed, together with the “predict-observe-explain” approach, involved the users in an active construction of knowledge, by probing the participants' descriptions and explanations.

In Multimedia Motion the users were asked to work collaboratively in twos (or threes) and follow the structure of the movie-based simulations of car and train crashes, people jogging, playing sports etc. This loose structure of the interaction was preferred, since the intention was to observe whether the students would use the simulations effectively, without a structured worksheet and a stricter time schedule.

3.5. Gravitas

In this section a description of the questionnaires and the worksheet used is followed by a description of observations of two learners using Gravitas.

3.5.1. Questionnaires and worksheet

Participants were first asked to give their views on gravitational attraction on a theoretical level. They were asked to answer the question:

Why do you think the Moon moves in an orbit around the Earth?

This question was related directly to the tasks they were to carry out during the interaction, since they had to think how one gravitational mass (the Moon) stays in orbit around another.

Next they were asked to go to the computer and carry out a number of tasks. The objective was to create a gravitational system which would

simulate the Moon's orbit around the Earth. An effort was made with the structure of the task to ensure that the users proceeded step by step and moved from the trivialities of the variables to the physics laws that govern the system. The above structure gave the problem a discovery-learning aspect. These tasks were adapted from similar tasks used by Sellman (1994).

3.5.2. The Task

Participants were given some initial time to familiarise themselves with the various buttons, controls and displays. They were then presented with an empty space and asked to construct a system representing the Earth being orbited by the Moon.

The users were given the mass and radius of the Earth and the Moon, as well as their actual average separation. All of the participants were familiar with the idea of x and y coordinates for position.

Then they proceeded step by step following the researcher's instructions and suggestions to carry out the following tasks. No printed copy of the worksheet was given to them because the intention was to surprise them with the succession of the tasks and elicit reactions to the simulated phenomenon on the computer screen.

- What do you think will happen when we start the system?
- Try to find a combination of velocities (x and y) that would make the MassOb Moon to orbit the MassOb Earth.

- Is there a better way of doing it instead of using trial and error?
- How could we calculate the correct velocity of the Moon around the Earth. Would this be the x or y velocity?
- Do you notice anything about the display on the screen?
- Why does the system you have built move up or down the screen?

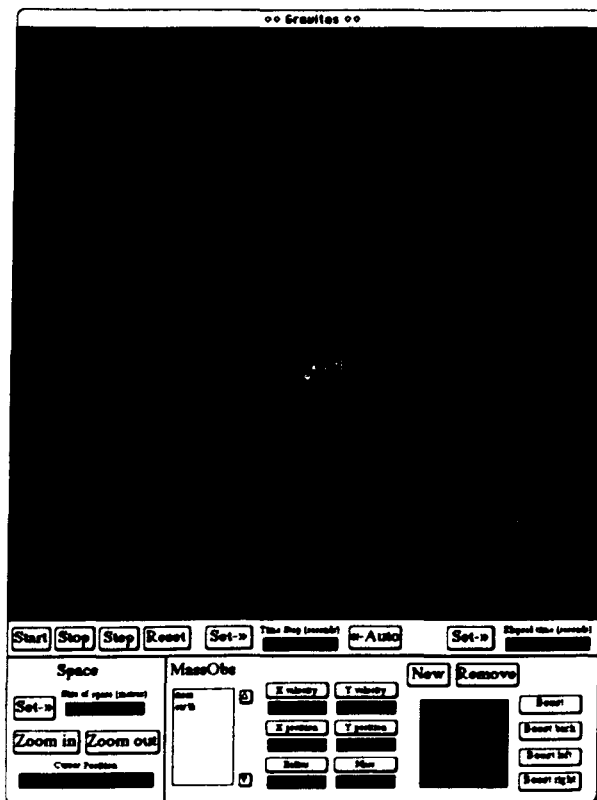


Fig. 3.1. Orbital Precession.

- What could we change in the system's data to eliminate this movement?
- Can you explain why the system is now staying in one place?

Subsequently, the video recordings of the users were transcribed. Table 3.3 shows the time the users needed to carry out the tasks.

| | |
|----------------|------------------|
| P1: Tassos | 45 mins |
| P2: Ben | 45 mins |
| P3: Brenda | 49 mins |
| P4: Kevin | 50 mins |
| Average | 47.3 mins |

Table 3.3. Time length of interactions with Gravitas.

The interaction reconfirmed what Sellman (1994) described as a common practice which people usually choose to build orbital systems. They put one stationary MassOb at the centre of the space and then position the second MassOb some distance away, with a velocity tangential to the first. None of the users of this study chose the trial and error method (except for one who slightly modified the results of her calculations by using trial and error to come up with a tangential velocity of the Moon). They calculated the x and y components of the tangential velocity correctly and ended setting up the Moon in an orbit around the Earth. It was at this point that the orbital system begins to move through space, in the same direction as the second MassOb's initial velocity, depending on the mass ratio of the two objects. So what usually starts as a straight forward exercise of building a gravitational system of a stationary MassOb and a second MassOb in orbit around the first one ends up as a system demonstrating an orbital procession upwards or downwards (Fig. 3.1).

Sellman (1994) provides an explanation of this orbital procession as a result of the violation of the conservation of momentum:

The procession occurs because of the initial conditions the subjects create, which are physically unrealistic. The system's initial momentum vector is due entirely to the second MassOb. In the absence of external forces the law of conservation of momentum tells us the system's total momentum must remain the same at all times. Therefore, as the second MassOb swings around the first, rotating its momentum vector, there must be a compensatory change in the momentum of the central object. At any point in time these two momentum vectors must add up to the original quantity.

(Sellman, 1994, p4)

The second part of the task set to the participants was to find a solution to the problem of the orbital procession. The users were asked to create initial conditions such that procession no longer occurred. The aim was to make them realise that for the system to have a stable orbit the law of conservation of momentum should also be obeyed.

It is true that Gravitas was not used to its maximum capabilities. One important aspect of it, the linguistic interface, was not used at all in the interactions. This was due to the time constraints (approximately one hour of interaction), which meant that the users could carry out tasks related to the graphical interface only and not use LOGO as an alternative option for communication with the simulation.

The next sections present transcripts and detailed annotations of two users' interactions with the system. Both of them were physics experts and their attitudes were representative of the sample who used Gravitas.

The first transcript is of Ben, a PhD research student. The session described took 45 mins to complete. Ben had a solid background in physics (his first degree was in physics). He carried out the tasks successfully.

3.5.3. Creating a MassOb System, P2: Ben

| Time | Learner activity | Comment |
|------|--|--|
| 0.01 | Creates the MassObs (first the Earth and then the Moon) on the screen. | |
| 0.05 | Puts the attributes of MassOb Moon | |
| 0.08 | Predicts that the masses will move towards each other when the system starts. | He is hesitant in committing himself to a prediction. |
| 0.12 | RUN. Increases the step from its original value to 500 and then to 900 after suggestion from the researcher. | |
| 0.20 | Searches in the controls for the current x and y velocities of the masses. | |
| 0.24 | Calculate the values that are needed from the physics laws applicable in this case. | Uses pen and paper to find the values. |
| 0.28 | Inputs the values of x and y of velocity he calculated. RUN. | Explains his calculations. |
| 0.33 | Observes the orbital procession. | Is prompted to explain the phenomenon by the researcher. |
| 0.35 | Calculates velocities of MassOb Earth. | Uses conservation law. |
| 0.39 | RUN. | Is satisfied that he eliminated the orbital procession. |
| 0.40 | Comments on Gravitas' features. | |

Table 3.4. Observation schedule of Ben for Gravitas.

Ben fared well in the pre test when he explained why the Moon moves in an orbit around the Earth: *"the centrifugal force of the orbit balances the gravitational pull of the Earth"* (Gravitas, Q1, P2, p3). His answer to the pre test question, why the astronauts only needed fuel for one seventh of their journey back to Earth, was incomplete though not incorrect: *"from there on gravity did the rest"* (Gravitas, Q1, P2,

p3). He did not wish to change or add anything to his pre test answers in the post test.

After having familiarised himself briefly with Gravitas, Ben began the task (Table 3.4 is an observation schedule of his interaction). He used both the mouse and the keyboard. He started by putting in the attributes of the MassObs (Moon and Earth). He created a geocentric system by placing the MassOb "Earth" in the centre of the screen (space) with co-ordinates 0, 0. Then he created the second MassOb "Moon", at the given distance horizontally to the right of the Earth. Before starting the system he predicted that *"the earth will move towards the moon and the moon will move towards the earth"* (Gravitas, Q1, P2, p8). He had to increase the step to get a reasonably fast orbit, as the simulation gives you the option to vary the step, increasing or decreasing the runtime, from real time to multiple values of it.

The next task was to find a combination of velocities (x and y) that would make the MassOb Moon orbit the MassOb Earth. He was encouraged to investigate if there was a better way of finding the velocities, rather than trying random values using a trial and error method.

He worked with a pen and paper to calculate the x and y components of the speed of the Moon. He came up with a zero component in the x velocity and a non-zero one in the y direction. He provided a thorough mathematical explanation of the two forces which determine the Moon's orbit around the Earth (Transcript 3.1).

P2. We work out the force of the gravitational attraction between the two bodies. Big m is the mass of the Earth and small m is the mass of the Moon. The Moon travelling in an orbit experiences a centrifugal force which is given by mv^2/r . So first step is $mv^2/r = GMm/r^2$. The m s on each side cancel out, one of the R s cancels out. Then we rearrange it in terms of v and putting in the numbers we have... And then I will use the values I found for the simulation, and we will see what happens.

Transcript 3.1.

(Gravitas, T, P2, p8/9)

Ben put in the values of the Moon's x and y velocities he calculated but before starting the system, he was asked to make a prediction on the system's behaviour. He predicted that the system would demonstrate a complete (full) circle and stable orbit. He was surprised at the outcome. He was at a loss in the beginning to provide some explanation of why the system he had built moved down the screen. His initial explanation was an incorrect one, as the following excerpt shows (Transcript 3.2).

P2. Let's wait for a while till it does a full circle. The Earth is moving... I always thought the...

Researcher. Why?

P2. The centre of the mass of the Earth is within the volume of the Earth so the Earth actually will move around.

R. Right, so the Earth is moving downwards.

P2. Wow!

Transcript 3.2.

(Gravitas, T, P2, p10)

He quickly realised that it was not just the Earth's movement which was not the expected one, but that the system moved together down the screen. He then was able to provide a correct explanation and a

remedy, which he would have to apply to the system, for eliminating this movement, as the following excerpt of his discussion with the researcher shows (Transcript 3.3).

P2. The system moves together, doesn't it?... Of course, now I see. I gave the Moon a momentum but I didn't give the Earth a momentum at all. So the system moves downwards.

R. What is it we could change in the system's data to eliminate this movement?

P2. We have to go back to the principle of conservation of momentum. The whole system has a downwards procession... It is because of the velocity of the Earth.

R. Which is how much?

P2. Well, initially it was zero. Since we want to stay on the screen and we gave a downward momentum to the Moon, we need to give the Earth an upward one, but since the Earth is much heavier...

R. How much will the initial momentum be?

P2. If you want it to be still the total initial momentum has to be zero.

R. So how shall we correct this?

P2. Just give the Earth a corresponding momentum.

R. Yes. How much?

P2. 12.27.

R. So?

P2. If we want the system to remain in the same place we need to give the Earth this velocity. Let's reset.

Transcript 3.3.

(Gravitas, T, P2, p11)

Ben was of the opinion that Gravitas was an interesting learning environment, since it gave him a feel about the behaviour of real gravitational masses in space. Furthermore, throughout the interaction his behaviour indicated that he interacted with the

simulation under the assumption that the computer screen (or better that part of the interface which represented gravitational space) represented real space.

3.5.4. Creating a MassOb system, P3: Brenda

The second annotated transcript is of Brenda. Brenda is a university lecturer with a background in physics, so she was familiar with the simulation's context. She was only momentarily surprised when she noticed the orbital procession. She explained the orbital procession successfully, and she modified the initial conditions in such a way that the centre of mass remained stationary.

Brenda provided a thorough definition of what the law of conservation of momentum is. She stressed that the condition would be the existence of a closed system and *"within a closed system, the total linear momentum of a group of objects remains the same"* (Gravitas, Q1, P3, p2).

In the pre test she also gave a precise explanation of why the Moon is in orbit around the Earth: *"because of the relationship between the gravitational fields and the angular velocity of the Earth and Moon"* (Gravitas, Q1, P3, p3).

She also provided a correct answer to the problem by stating that the astronauts did not need any fuel after they had completed one fraction of the journey back to Earth because *"by that stage they must have re-entered the Earth's gravitational field and could return to Earth otherwise unassisted"* (Gravitas, Q1, P3, p3).

| Time | Learner activity | Comment |
|------|---|--|
| 0:00 | Investigates features of the interface (form in which data are accepted, etc.). | |
| 0:04 | Creates MassOb Earth. | Selects as position Centre of Screen. |
| 0:06 | Creates MassOb Moon. | |
| 0:07 | Predicts motion of MassObs. | |
| 0:08 | RUN and discusses with R. the MassObs' behaviour. | |
| 0:12 | Calculates x and y components of Moon's speed. | Uses pen and paper for calculations. |
| 0:23 | RUN. | Tries out values of x and y. |
| 0:26 | Discusses with R. about system's procession. | |
| 0:30 | RUN. | Tries out values of velocities for the Earth. |
| 0:35 | Explains her calculations. | The system must obey conservation of momentum law. |
| 0:40 | Discusses preferences and her opinion of the interface. | |

Table 3.5. Observation schedule of Brenda for Gravitas.

She decided that the system she had to create could be a geocentric one since it involved just two MassObs. She also chose to put the masses on a horizontal line (Transcript 3.4).

P3. What about the velocities?

Researcher. You can forget now about the velocities, but you must put in the radius and the mass. Also where you want it to appear on the screen.

P3. If I want it to appear....

R. You must define the x and y position.

P3. I suppose I can have a geocentric system.

R. It's on your screen now.

P3. I have to make a decision where to put the Moon. If I have axes like that it will be x distance and it will be zero for y.

R. Why did you make this decision?

P3. Just because it saves typing.

Transcript 3.4.

(Gravitas, T, P3, p12)

Before starting the system she was encouraged to make a prediction about the system's behaviour. She replied that conditional to "*the system having gravity built in*" (Gravitas, T, P3, p13), the masses would collide. When she started the system the masses collided but in effect it appeared that the MassOb Moon went straight through the MassOb Earth. Transcript 3.5 shows how Brenda negotiated with the researcher a possible explanation of the "odd" behaviour of the system.

R. Let's increase the step because it's really small now.
It's moving...

P3. Ah, it went straight through the Earth. It wouldn't do that, would it?

R. In fact it's the first time I see that. . What happened there is that it's gone through...

P3. Well, it appears to pass through but now...

R. Is it coming back?

P3. No, it went through but it's given the Earth some momentum and the Earth is going in the opposite direction. It doesn't seem very likely. Because apart from anything else the Earth would break up, wouldn't it?... Right.

Transcript 3.5.

(Gravitas, T, P3, p13)

In this part of the interaction there were two instances of the user alluding to the underlying model of the simulation. In the first case the allusion was direct when Brenda described the simulation as a system which "*has gravity built in*" (Gravitas, T, P3, p13). When the

behaviour of the simulation failed to confirm her expectations, she again alluded to the simulation's underlying model indirectly, this time by disagreeing with the behaviour of the system: *"It wouldn't do that, would it?"* (Gravitas, T, P3, p13).

Brenda then proceeded to set the MassOb Moon in orbit around the MassOb Earth. Her comment was that having *"real figures for everything"* she also needed *"something real for the velocity"* (Gravitas, T, P3, p13). She calculated the Moon's velocity components using pen and paper.

She immediately realised after starting the new system that there was a procession on the computer screen (Transcript 3.6).

P3. Well... The very interesting thing... The orbit is all right but the Earth is processing.

Transcript 3.6.

(Gravitas, T, P3, p13)

The next step for her was to observe the orbit of the MassOb Moon and take into account the conservation of momentum law. She also realised from observing the system that the actual orbit was not around the centre of mass of the MassOb Earth but around the centre of mass of the system, as the following excerpt of the interaction shows (Transcript 3.7).

R. Can you explain what you are doing?

P3. What I am trying to do is a question of getting things in the right direction... I used the conservation of linear momentum taking the velocity that I had for the Moon and I calculated a velocity for the Earth and then split in x and y components in about the same proportion I split the other one, the Moon and look at that... Not bad. And just actually put them in the opposite direction so when I got positive y and negative x for the Moon, I put it the other way for the Earth. That's a thing I was not really sure about... It's all right. Except though it looks as a circular orbit, the Earth is not the centre of it.

Transcript 3.7.

(Gravitas, T, P3, p13/14)

Her explanation of her approach to carrying out the task highlighted examples of her attitude towards the simulation. The two important factors were her prior knowledge of the context and how she used this knowledge to modify aspects of the system (Transcript 3.8).

P3. I used things that I know about the real system and then did some calculations to put in there on the assumption that the other behaviour that I could not influence, was also based on a real system. I think that I was believing that I was given a program in which if I built a system using the real data about the mass and so on. Because the gravitational things are for real. I then modified the system by using something else about the real system. And it's now roughly what the Moon does, but the real system does not have a circular orbit, does it? I am not sure how... In that sense I think I believe that whatever someone put in there, the gravitational aspects did actually reflect the real system. The real behaviour.

Transcript 3.8.

(Gravitas, T, P3, p14)

Brenda carried out the tasks without difficulty and interacted with Gravitas under the assumption that the simulation was a faithful

imitation of a real system whose behaviour reflected reality. She accepted the formalisms of the interface (dots and circles) as representational metaphors. She made frequent allusions to the simulation as a black box programmed to behave like a real system.

3.6. Multimedia Motion

The second learning environment, Multimedia Motion (MM), was chosen as it represented a different approach to Gravitas in terms of visual representation. Instead of points, circles and vectors as conventions of physical representation it used a real life context of video sequences from which the users were expected to draw information and collect data (MM was described in detail in Chapter Two).

An evaluation of MM was conducted as part of a large scale developmental study. The evaluation consisted of observations of student use and students interacted in an open-ended manner, in loosely structured task oriented sessions. The results of the study were encouraging for MM but the students' use of the MM sequences was rather unstructured (Whitelegg et al, 1997). In this study a similar methodology was followed to investigate how students negotiate without teacher intervention while observing the simulation and manipulating its variables.

3.6.1. Questionnaires

Questionnaires similar to the Gravitas ones were completed by the Multimedia Motion users. They were asked about their previous

experience with computers and computer simulations and to give their views on conservation laws on a theoretical level.

3.6.2. The worksheet and the tasks

There were no structured worksheets for MM. The users were given a text combining theory, problems and tasks and they worked through them following a loose schedule. Descriptions of the tasks that were used are given in the annotated transcription of interactions, in the next sections.

Table 3.6 shows the time the users needed to carry out the tasks during the interactions:

| | |
|-------------------------------------|-----------|
| P5, P6: Li, Darren | 55 mins |
| P7, P8, P9: Gabriel, John, Steve | 50 mins |
| Average | 52.5 mins |

Table 3.6. Time length of interactions with Multimedia Motion.

The simulated lab, P5: Li and P6: Darren

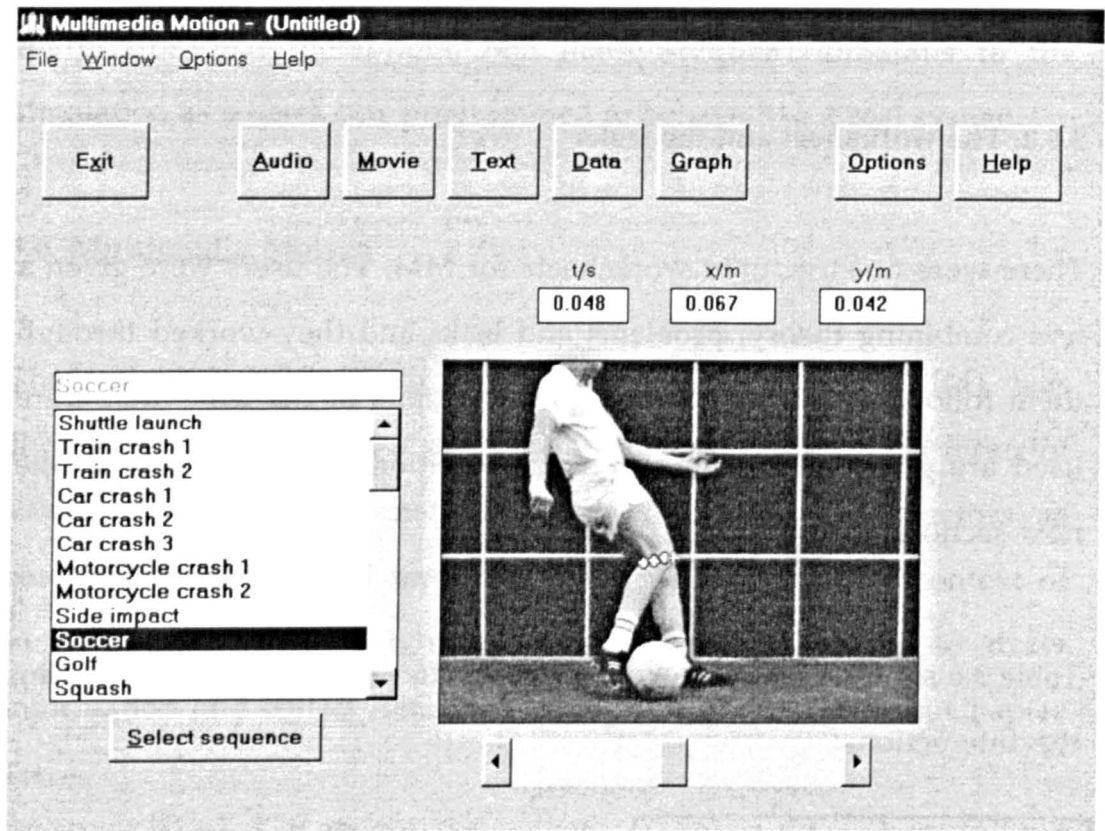


Fig 3.2. MM: Soccer.

Li and Darren worked with two sequences. The first one investigated impulse. It showed a man kicking a soccer ball (Fig 3.2) and they were asked to calculate in a logical progression, for how long the foot had been in contact with the ball, the ball’s velocity just after it left the foot, and the impulse (and therefore the force) with which the ball was kicked.

The users followed step by step the calculations that were required for the average force, and then they moved on to Air Track Collision 5 where they had to investigate what happens to the momentum and kinetic energy for each of the gliders after collision. In both sequences the irregularity of the points on the graph made them doubt whether

| Time | Learner activity | Comment |
|------|---|---|
| 0.00 | Select the sequence Soccer. Click on the screen to collect data. | Darren operates the mouse. |
| 0.02 | RUN. Make plots of the ball's position just after it has left the kicker's foot. | |
| 0.05 | Look at the graphs of velocity. | Find difficult to discern any patterns. |
| 0.10 | RUN. Read the MM's textual information. | |
| 0.15 | Calculate average force, using the spreadsheets. | Are not satisfied with the results. |
| 0.21 | Examine again spreadsheets and the sequence frame by frame to determine contact time of the foot and the ball and average velocity. | |
| 0.28 | | Stop as they decide that was the best they could do in this activity. |
| 0.33 | Air Track collision 5. RUN. | |
| 0.35 | Choose a random point on the second glider. | No visible pattern of clickings on the screen. |
| 0.38 | | Discuss how to investigate what happens to the total kinetic energy. |
| 0.41 | Do calculations of mass times velocity before and after the collision using their data. | |
| 0.46 | | There is discrepancy between their calculated values of before and after. Decide to stop. |

Table 3.7. Observation schedule of Li and Darren for Multimedia Motion.

the velocity of the ball (and therefore the calculated force) was calculated correctly. In Air Track Collision 5 there was a discrepancy between their calculated result (final kinetic energy smaller than initial one) and their expected conservation of kinetic energy outcome. Their difficulty in interpreting correctly the graphical representations had an effect on the perceived validity of their calculations.

The simulated lab, P7, P8, P9: Gabriel, John and Steve.

Gabriel, John and Steve worked together as a group, with 5 sequences of MM (Table 3.8). Gabriel was the motive force behind the group's activity, suggesting new ideas and making choices for the group. Steve on the other end was very quiet, his input in the experiment was minimal.

They moved fast between sequences, not engaging with the content for very long. They began with the sequence Air Track Collision 1 (moving mass collides with stationary one). They were asked to make plots of position, compare the velocities before and after, investigate how well the law of conservation of momentum is supported in the sequence and compare it with another collision sequence. As they were not happy with the graphs that corresponded to their collected data (they could not discern any reasonable pattern), they ended calculating average velocities pre and post collision, using a calculator. They moved to the next collision sequence without reaching any conclusion for Air Track Collision 1.

In the second sequence, Air Track Collision 2, they calculated again average velocities from the spreadsheet, only to move to Air track Collision 13. In the following transcript they discuss the heuristics of a successful graph, realising that well chosen clicks on the screen result in better graphs (Transcript 3.9).

| Time | Learner activity | Comment |
|-------|---|--|
| 0.10 | Air Track Collision 1. Plot points on the screen (9 points). | John operates the mouse. Gabriel seems to be directing their actions. Steve very quite. |
| 0.12 | Examine the spreadsheets and velocity and accelerations graphs. | Have difficulties in understanding the graphs. |
| 0.14. | Examine again the spreadsheets. | Attempt to find the exact point when the collision happened. |
| 0.17 | Calculate average velocities before and after. | |
| 0.18 | | Stop and choose another sequence. |
| 0.20 | Air Track Collision 2. Collect data. | |
| 0.24 | Calculate average velocity before collision. | |
| 0.26 | Calculate momenta. | Investigate conservation of momentum. Are not happy with the results. Decide to have another go with another sequence. |
| 0.30 | Air track Collision 13. RUN. Read the task. | Task: "why the small mass bounces back so energetically". |
| 0.32 | | Gabriel provides an explanation why. |
| 0.34 | Air track skier. Read the accompanying text. | Task: make measurements to calculate relative masses of the skier sequence. |
| 0.36 | Choose point on the pendulum. Collect data. | |
| 0.39 | Examine data (graphs and spreadsheet). | Decide to try the Train Crash. |
| 0.43 | Train Crash. Read accompanying text. | Answer questions in the text. |
| 0.47 | | Cannot understand where on the screen is the flask mentioned in the text. |
| 0.50 | | Decide to calculate the initial acceleration of the flask. |
| 0.55 | Collect data by clicking on what they suppose to be the flask. | |
| 0.56 | Look at graphs. | Try to discern a pattern on the acceleration graph. Cannot. |
| 1.00 | Calculate acceleration dv/dt . | |

Table 3.8. Observation schedule of Gabriel, John and Steve for Multimedia Motion.

- P7. What happened?
- P8. Do you want to get the velocity for before and after.
- P7. We'll have to do them separately as the green one keeps moving afterwards.
- P8. No, wait.
- P9. If we haven't got the masses, how are we going to do that?
- P7. If you know that it's probably travelling at a constant velocity, you can probably do the blue one now.
- P8. From here.
- P7. Yeah, but I know it won't make a nice graph... Can you get one more?

Transcript 3.9.

(MM-pilot, T, P7-P8-P9, p17)

The next sequence was the Air Track skier, where they were asked again to investigate momentum with linear track vehicles. After they collected points on the screen, they examined spreadsheets and graphs, and moved to the Train Crash sequence, where they were asked to find the acceleration of a part of one of the trains. They had difficulty finding on the computer screen the exact part of the train whose acceleration they had to investigate. The same ritual of collecting data, examining graphs and rejecting them, only to use the spreadsheet to calculate averages was followed. They put a value equal to the acceleration by calculating dv/dt from the spreadsheet data.

Gabriel, John and Steve did not use the sequences as intended, moving continuously from one sequence to the next, rather than completing the relevant tasks. They found it difficult to interpret the graphs, or deduce outcomes from studying the spreadsheets. Their

approach to using the collected data was calculating averages of the simulation's variables from the corresponding spreadsheets.

3.7. Findings from the study: Reality and Underlying model

3.7.1. Analysis of attitudes to the simulations

MM's "real world" interface was designed to increase motivation and engage users and it seems that it succeeded in that respect since the participants of the study moved with anticipation from sequence to sequence. However, their use of the simulation was unstructured. They quickly abandoned unresolved problems in each sequence and moved to the next, setting themselves new goals. They would embark on the ritual of screen clickings, visiting the spreadsheets and the graphs, but were reluctant to make calculations and engage with the content of each sequence. The users also had difficulties in interpreting the MM graphs that their data produced. This in most of the cases made them return to the spreadsheets and use them instead to make calculations.

In Gravitas, the users' performance was indicative of how the experts test their abstract mathematical reasoning by verifying their results in the simulation. They used the simulation to verify the outcomes of their calculations, expecting the interface's behaviour to confirm their expectations.

3.7.2. Interface

The users of the study showed signs of accepting the simulations as representations of reality. For Gravitas, on the whole, the users agreed that it was a successful representation of gravitational interaction between masses in real space. An example of such a comment was: *“Very useful, it shows immediately what the real system will behave like. And the graphics are much more interesting than just working out some arbitrary numbers. With more bodies it can also be used to model very complicated real systems.”* (Gravitas, Q2, P2, p7).

Gravitas' schematic representation did not confuse the users, as they interacted with the system without forgetting the complexity of reality: they often referred to the fact that motions in real space are more complex than those in Gravitas: *“...for the real Earth-Moon system, many other bodies are present (all the planets, Moons asteroids and the sun). Also the Earth is itself in orbit around the sun. All these things make the real system considerably more complicated”* (Gravitas, Q2, P2, p6).

The comments of the users on MM were also positive. They appreciated its realistic interface, which sometimes though was frustrating, either because of the *“not clear”* video screen or because of difficulties in reading the graphs. An example of a comment on the graphs was: *“it was difficult to see how the sequence corresponded to the graph, mainly with acceleration which changed so erratically on the graph.”* (MM-pilot, Q2, P6, p18).

The experts in Gravitas did not expect to be taught by the system. They used the simulation to confirm the validity of their predictions and verify the results of their calculations. As one of them commented: *"Useful to check theory by seeing if the answers are correct"* (Gravitas, Q2, P4, p7) and, describing their experience, *"I used things that I know about the real system in order to make calculations to put in there. It's like building systems using the real data."* (Gravitas, T, P3, p6).

Some of the users agreed that the systems could help learners to investigate physical laws. An example of such a comment was: *"I think that trying to succeed in any specific task will help somebody to reveal what's going on with the physics behind it"* (Gravitas, T, P1, p7). But others thought that the experience was inferior to observing the same phenomenon in the physics lab: *"seeing something for yourself in real life makes you to believe it more"* (MM-pilot, Q2, P8, p18). They also expressed doubts regarding some aspects of the behaviour of the masses. In some cases they made a distinction between the behaviour of masses in the simulation and the behaviour of similar objects in reality, e.g. for Gravitas: *"It's not representative of the real system because the Moon's orbit around the Earth is not circular but elliptical. An elliptical orbit would be a truer representation. The other planets' effect is also minimal."* (Gravitas, T, P2, p10). They also referred to conditions which could affect the behaviour of masses (e.g. friction in MM).

The study did not help in a definite way to determine which factors in the interface's design promote learning and acceptance of the simulation by the users.

3.7.3. Underlying model

As “cleaned-up” versions of the real world, simulations have laws which only approximately apply to real world situations. The implication is that learners may become involved in making changes randomly instead of purposefully manipulating variable and parameter values, e.g. users in Gravitas eliminated non-predictable features in the planets' orbit by making changes to the values of variables randomly.

The users, in both simulations, referred to the underlying model as a set of properties built in a system, for instance Gravitas “*had gravity built in*” (Gravitas, T, P3, p12) or as a number of physical laws that the system obeyed: “*The system just applies physical laws*” (MM, Q2, P9, p18).

Perhaps their perception of the model underlying a simulation would be different if it was possible to change the properties of the underlying model (taking part in the modelling themselves), or if they were presented with a number of alternate realities.

3.8. Conclusion

A combination of experts and novice students participated in the study's interactions and differences in interaction style and different approaches to the simulation were noted. Two different behaviours were observed.

The experts of this study (in Gravitas) did not rely on interface or visual representation so much, but used their knowledge about the underlying model for interacting with the simulation. During their interaction they were constructing mathematical abstractions, and expected the interface's behaviour to confirm their expectations. They were oblivious to whether the interface was realistic or not. They used the simulation to verify the outcomes of their calculations. This does not mean that they did not make mistakes. In fact, confident as they were, they often misjudged a physical situation and expressed erroneous opinions.

Non-experts followed a reverse procedure. Their interaction protocols showed no sign that they had any perception of what the underlying model looked like. They used the interface to extract information on the variables' values. The interface was, to them important as the medium by which they could explore the underlying model. They tended to use "trial and error" methods to complete tasks. They had difficulties in relating their calculations to the physical theories and principles, and, in deducing from them correct conclusions.

The results of the study implied that an instructional cycle similar to the ones described in Chapter Two would work best with simulations. The predict-observe-explain approach used with Gravitas provided encouraging results in keeping track of the participants' conceptual change and it was decided that it should be used again with the following studies in this thesis.

The study indicated that interactions with pairs in the main study might be more fruitful in encouraging talk than interactions with

individuals in front of the computer. In Gravitas continuous intervention and prompting was needed from the researcher to elicit explanations from the users. In MM, pairs and groups of students were the participants and though their contributions to the task completion were unequal they worked collaboratively, exchanging comments and suggestions. Interactions with both simulations also indicated that users would benefit from the use of a structured worksheet. Consequently the use of structured worksheets with tasks to be completed in a reasonable time was decided for the following studies, where the students would potentially engage with the content more constructively.

The comments of the participants of the study in the post test questionnaires and in the interaction transcripts were useful in suggesting which aspects of the simulation might be motivational or effective and in providing information about users' perception of realism of the simulations. Consequently, a more extensive investigation of users' perceptions was decided by the use of lengthier questionnaires and interviews, combining aspects of learning and usability towards an evaluation of educational software.

The preliminary findings addressed indirectly the issue which was of main interest to this research: how to design effective computer simulations which would mediate between the observable and the Newtonian world, using which the users can achieve successful interactions. An important component of this design, the simulation's interface can facilitate the familiarisation with physics abstractions by linking external representations (which relate to students'

experiences) with numerical and graphical representations of the underlying model.

The initial investigation in this chapter examined two interactive simulations, in which representation of physical knowledge is used for communicating concepts, laws and principles to the users with alternative views to those of the physics expert. Two factors were considered which can play a significant role in conveying this representation: the interface as a measure of “what the simulation looks like” and the underlying model as a measure of “how the simulation behaves”.

The next chapter is an overview of the research on representation in simulations. This overview led towards a consideration of a theoretical model, which would serve the purposes of this research and could also be used for classifying computer simulations. Degrees of visual fidelity combined with levels of representation of the underlying physical model could influence the users’ frameworks and help them to negotiate effectively with the learning environment. To test this model a practical study took place, where educators and designers theorised on how these variables could be applied to the description of computer simulations.

Chapter Four

Fidelity and complexity

4.1. Introduction

In Chapter Three, studies of users interacting with a number of simulations were described. Those studies illustrated some useful factors in categorising simulations: the interface as a visual representation of the invisible underlying model in the simulation's black box, of which the users can catch a glimpse, by observing the objects of the simulation in motion and by deducing the simulation laws from the expression of variables. The need for a framework from which to consider representation led to an overview of the existing theories on fidelity and the construction of a suitable theoretical model.

The chapter begins with an overview of these fidelity theories, from which this research borrowed in order to establish a framework of two variables as co-ordinates of the perceived reality. These variables, **fidelity** and **complexity**, are described in detail and applied to the simulations already described in Chapter Two. This is followed by a small case study with educators and designers, in which they evaluated interfaces and discussed fidelity and complexity. The purpose of this study was to receive feedback from the experts whether the issues this research was concerned with were of relevance to the design and successful use of computer simulations.

4.2. Fidelity theories

Fidelity: the fidelity of an adaptation or translation is its **degree of accuracy**.

(Sinclair, 1993)

Fidelity, a dictionary definition of which is given above, is used to refer to a match between simulations and reality. In this section a number of theoretical approaches to fidelity will be examined. An attempt is made to present the fundamental components of each theory briefly and critically. The order of presentation is not chronological, but it follows an increasing relevance to the issues addressed in this research. The general purpose was to show that the approach this research has taken evolved from aspects of these theoretical frameworks. The theories are summarised in Table 4.1.

| FIDELITY THEORIES | | |
|--------------------------|---|---|
| Allen (1986) | Training simulator fidelity | Simulator "looks like" and "acts like" the real equipment |
| Wenger (1987) | Epistemic fidelity | Conceptual rather than a physical view of a model |
| Roschelle (1994) | Mediating Collaborative Inquiry vs Epistemic fidelity | Supporting communicative practices rather than representing mental models |
| De Hoog: (1991) | Input fidelity output fidelity | Data input Vision and sound |
| Alessi (1988) | Taxonomy of fidelity considerations | Underlying Model Presentations User Actions System Feedback |

Table 4.1. Fidelity theories.

4.2.1. Allen: Training simulator fidelity

In a study which investigated the relationship between simulator fidelity and training effectiveness, Allen (1986) used simulators for training people to perform a simple mechanical adjustment task. In his research the concept of fidelity, as defined by Hays (1980), describes the degree of similarity to the actual equipment. The aspects of fidelity which were used and manipulated in the above study were: **physical fidelity** as the degree to which a training simulator “looked like” the actual equipment it was simulating, and **functional fidelity** as the degree to which it “acted like” the real equipment.

Allen’s (1986) concern was that previous research had evaluated the effectiveness of full-fidelity devices rather than systematically investigating the effect of various degrees of fidelity, so his theory was significant, in that he introduced the notion of varying fidelity for enhancing learning. The results of his research on training simulators probably have limited applicability to computers, but his use of physical and functional fidelity to describe the dimensions of fidelity remains interesting and inspirational to other researchers, like Alessi (1988).

4.2.2. Wenger: Epistemic fidelity

Wenger (1987), in his examination of expert mental models, refers to simulations which attempt to communicate these models, and he uses the example of STEAMER, a steam propulsion plant. The tool of his analysis is the notion of **epistemic fidelity** (Hollan et al, 1984), where the view of the interface in a simulation is meant to reflect less

an exact physical model than a mental model as used by an expert. This is the principle of conceptual fidelity, i.e. to render a conceptual rather than a physical view of a model. A simulation model is conceptually faithful to the extent that its presentation illustrates the conceptual abstractions that experts seem to use in reasoning about a system, rather than the system itself. The pedagogical claim is that running a conceptually faithful simulation can be considered a form of continuous explanation, since it reflects an expert's view of phenomena.

In STEAMER the application of the principle of conceptual fidelity does not go beyond the interface. STEAMER's underlying model is purely mathematical and it is converted into qualitative concepts by means of graphic representational schemes and associated procedures (Wenger, 1987). Thus STEAMER provides an inspectable abstract view of a quantitative model by using top level views and icons.

In his review of another system, QUEST (a learning environment using simulated electrical circuits), Wenger makes the point that this time, the principle of conceptual fidelity is carried beyond the interface into the internal representation: an internal representation of qualitative models is used to generate explanations. Thus the conceptual fidelity concept is enriched by the use of Artificial Intelligence principles.

4.2.3. Roschelle: Mediating Collaborative Inquiry versus Epistemic fidelity

Roschelle (1994) presents a critique of the epistemic fidelity notion and provides a domain-related explanation why increased epistemic fidelity (as in Wenger, 1987) does not always enhance transfer of learning, using physics as an example. In his approach he differentiates between the expert-physicists' knowledge, i.e. those who "link every element of their mental model to a single abstract mathematical definition", and the student's knowledge, which is composed of "relations among many fragmentary qualitative cases and metaphoric abstractions". He concludes that it is quite unlikely that these "naive" views of the students could be overcome by strong epistemic fidelity. He argues that a better picture of the expert mental model is not likely to be enough to encourage students to construct mathematical definitions instead of qualitative cases and abstract metaphors. In other words, a better picture is unlikely to change students' preferences for local instead of global regularities and for fragmentary, adaptable knowledge over compact and consistent knowledge.

So, he introduces instead the notion of **Mediating Collaborative Inquiry** (MCI), claiming that designers must focus on supporting communicative practices, by designing a medium which facilitates collaborative inquiry, rather than representing mental models more or less accurately. In his theory, there are implications which connect MCI to situated learning, where the social and cultural contexts are a crucial part of learning (Brown et al, 1989; Jones et al, 1997), though they do not become explicit.

Though the emphasis on communicative practices that enable collaborative learning is important and educational software's effectiveness is dependent on the instruction cycle (see 2.6.2), claiming that collaborative practices can exclusively promote conceptual understanding underplays the value of consistent, well designed interfaces, which purposely convey in their design degrees of epistemic fidelity.

4.2.4. De Hoog: Input and output fidelity

De Hoog's fidelity (de Hoog, de Jong & de Vries, 1991) is defined as an attribute of the learner interface, as the fidelity level of the representation on the screen, drawing from Cunningham's (1984) definition: fidelity means the resemblance between the (physical) appearance of the simulation and the "real world" model it simulates.

According to this approach there are two criteria on which fidelity can be assessed. The first one is how closely the underlying model resembles the "real world" model. The second criterion refers to the "look and feel" of the simulation and has three dimensions:

1. **Output fidelity**, i.e. does the output of the system resemble the modelled system closely (in vision and sound)?
2. **Input fidelity**, or is the way input is provided the same as in reality, both in the kind of data input as well as the way this is done? and
3. **Time fidelity**, or if the runtime of the simulation equals the timing as found in reality

In the above model the correspondence between the real world and the model in the simulation creates the basis for the fidelity level of the simulation.

4.2.5. Alessi: taxonomy of fidelity considerations

Alessi (1988) discusses the issue of whether fidelity should be high or low depending on particular students and materials. His notion of fidelity is presented as prescriptions of what should be higher or lower in fidelity. These prescriptions take the form of a taxonomy of factors to consider in determining simulation fidelity. His is a two dimensional space where one dimension (horizontal) represents four aspects of simulations to which fidelity is relevant, and the other (vertical) is a categorisation of simulations as physical, process, procedural and situational (Table 4.2):

| Underlying Model | Presentations | User Actions | System Feedback |
|---|--|--|---|
| -number of objects -cause-effect relationships | -detail/realism of representations -visual versus textual representations -illusion of motion -time frame | -user control versus natural progression of the phenomenon | -mode of feedback -immediacy of feedback -whether there is any feedback at all -exaggeration of feedback magnitude |

Table 4.2. Alessi’s taxonomy of physical simulations.

In the first column of Table 4.2, **Underlying Model**, fidelity considerations lead to a consideration of the objects inherent in the phenomenon and the rules underlying their behaviour. In the second column, **Presentations**, primary considerations are the visual and

audible stimuli and the time frame in which events occur - most simulations speed up or slow down events. In the third column, **User Actions**, fidelity concerns the number and type of actions the student may engage in. In the fourth column, **System Feedback**, considerations include whether there is any feedback, whether it is immediate or delayed, and whether it is realistic or artificial.

For the purposes of this research only the physical simulations, which deal with physical object or system of objects and their behaviour about which we want the students to learn, are of interest. Alessi (ibid.) points out that the first two columns in his taxonomy are more important for physical simulations' design, since the instructional objectives concern learning about the phenomenon and the theory underlying it.

In his research he compares computer simulations to mechanical simulators, such as Allen's (1984), arguing that viewing a simulation on a computer screen and interacting through a keyboard is very low fidelity in comparison to training simulators. This is an argument though which probably could not predict (in 1984) recent sophisticated interface designs and the advent of virtual reality.

4.3. Research on the relationship between fidelity and learning

The relationship between fidelity and learning in computer simulations is not necessarily a linear one. There are a variety of theories relating fidelity to learning. Some of them, especially by the early simulation theorists, did relate learning and fidelity almost linearly. They suggest that increasing fidelity will increase transfer,

and that high fidelity yields high transfer; so increasing fidelity should increase transfer of learning (De Hoog et al, 1991). In terms of computer interfaces a typical attitude of this type is that “a simplistic interface may evoke no curiosity from the learner”. Other theories support the view that as irrelevant detail is added to an interface, learning decreases, because too much realism may detract from the learning experience, producing a scanning syndrome among learners in which they focus on nothing. Researchers like Reigeluth & Schwartz (1989) position themselves between the two views and differentiate between certain aspects of the real world situation which should be represented with high fidelity in the simulation and others which need not, and should not. They make a distinction (ibid.) between the “fundamentals” of the real situation and its more artificial aspects which may create overload, impeding learning and motivation.

4.3.1. High fidelity: research evidence

After the development of Graphical User Interfaces (GUI), at the end of the command line “era”, the computer interface theories borrowed from the generic theory of simulators. In computer simulations, the theories on “similarity” were influenced from the most famous simulator, the flight simulator.

Early theorists adhered to the general notion that increasing fidelity would increase transfer of learning. Robinson (1927) proposed a U-shaped curve: very low fidelity would lead to moderate transfer, medium fidelity would lead to negative transfer, and high fidelity to high transfer. The notion was that high physical similarity may be

very important for maximum learning transfer (Baum et al, 1982), since not only tasks which need to be transferred to reality would profit from a high fidelity level but also the level of motivation might be enhanced by a high fidelity level.

Several theoretical frameworks suggest variable levels of fidelity that can be chosen according to the knowledge level of the learner, e.g. Miller (1974) maintains that fidelity effects depend largely on the instructional level of the learner. Similarly, Alessi (1988) differentiated between expert, experienced and novice students. He suggested (ibid.) that maximum fidelity does not necessarily provide the most effective instruction and indicated that “increased fidelity does not always enhance transfer of learning”. He proposed instead a relationship between fidelity and transfer of learning where learning varies with fidelity as an inverted U-shaped curve for novices (Fig. 4.1).

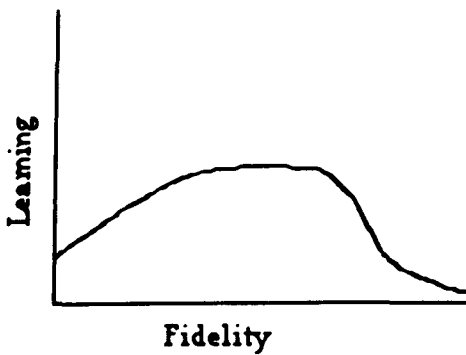


Fig. 4.1. Hypothesised relationship of fidelity and learning for novice students, Alessi (1988).

Finally, De Hoog (1991), in his view of fidelity, suggested that the question should rather be whether high fidelity levels are necessary for understanding the processes involved in a simulation.

4.3.2. Low fidelity: research evidence

Alessi (1988) in his exploration of the two aspects of the fidelity variable in relation to the level of the learner-user indicated that during the early stages of learning a high fidelity representation may tend to confuse a trainee because of the rapid presentation of complex sequences (full reality might be overwhelming for novice learners).

For novices, it might be sensible to replace the simulation model with a stylised pictorial representation, highlighting some of its characteristic features. Simulations that are too realistic and complex may not permit the identification of the underlying model. The advantage of lowered-fidelity simulations, as described by Williges & Roscoe (1973) is a combination of “planned variation of various elements of the real situation” with “unessential variables in the real situation omitted”; that is, essential features are attended to better if other features are removed.

4.4. Fidelity and complexity as dimensions of the perceived reality

An important question in designing a simulation is, “to what degree should we try to emulate reality?”. However both the visual representation and the underlying model of the simulation should reflect the situation being simulated. A related question is, “what is the point between abstraction and reality that defines the ideal interface?”. Should the attempt always be to create maximum fidelity, or is it sometimes more effective to alter or simplify reality?

(Reigeluth & Schwartz, 1989). Two variables which could describe this emulated reality are **fidelity** and **complexity**.

4.4.1. Fidelity

In a simulation, there is not necessarily close correspondence between the simulation and the simulated; so a simulation can just consist of counters where the students can input numbers and get results, or it can be a realistic representation of a phenomenon, using animation or video. The variety of image types used can be wide, moving along the dimension from still to video (Whalley, 1995) and from virtual to real (Fig. 4.2).

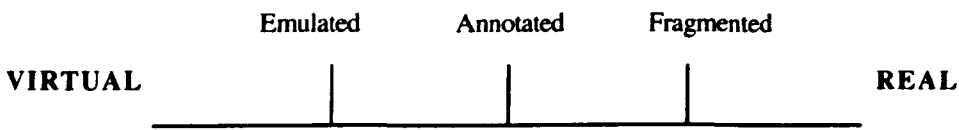


Fig. 4.2. Image types (Whalley, 1995).

For the purposes of this research, a distinction was made between the visual fidelity of the simulation and the degree to which the underlying model conforms to reality. The Alessi model (1988) was considered to be the most appropriate among the models that were considered, since it attempted a comprehensive taxonomy of fidelity. Two variables, fidelity and complexity, were derived from two aspects of his taxonomy, namely “underlying model” and “presentations”.

The term fidelity in this research will be used to assess interfaces in relation to:

- **detail or realism of representations.** This includes not only the way objects are represented on the screen but also the way the motion of an animated object conforms to the motion of real phenomena.
- **the ambiguity of the representation,** i.e. the use of idealisations of the represented objects and not a photographic representation, e.g. points representing masses moving on the screen.
- **time fidelity,** as used by De Hoog (1991) to describe the comparison between the runtime of the simulation and the timing as found in reality, similarly as used by Alessi (1988) in his taxonomy as the time frame in which events occur.

In the above theoretical framework, the variable fidelity is also related to the user control versus natural progression of the phenomenon; the user's control over the simulation can vary from just collecting data from the simulation without being allowed to choose values of variables, to the point where she can choose from a wide range of values of variables and observe the effects of her choices on the screen.

Fidelity might be affected by other factors as well, in cases where the simulation computer screens are hybrid ones. In hybrid screens the interface consists of images imitating the observable world in combination with mathematical manipulations of the underlying model: mathematical symbols, graphs etc. Then additional factors which may affect fidelity are:

- the use of mathematical and physical symbols in the interface (e.g. vectors, physical symbols, units, graphs) and
- the use of feedback correcting input errors.

The issue of hybrid screens is an important one since a clear screen, irrespective of the level of fidelity, cannot provide a sufficiently informative environment without multiple representations, graphs, timers and digital counters which transform the physical reality for the student into measurable outcomes, using which she can have views of the underlying model.

An attempt to relate fidelity and complexity to Wenger's (1987) model of conceptual fidelity would be that of considering conceptual fidelity as a whole, whose components would be this research's fidelity and complexity.

4.4.2. Complexity

The second variable, descriptive of the reality of a simulation, is complexity. In a simulation the underlying model is represented by a number of variables used (which can vary in number), the mathematical equations with which these variables are interrelated and how complex these equations are, resulting in a variable degree of complexity of solutions.

Complexity refers to how complex the physical model underlying the simulation is, in terms of the physical laws describing the simulated phenomenon and complexity of implementation. Complexity is influenced by the level of precision of physical theory.

The two variables are not independent. There are overlaps with some of the components of the above definitions. So an increase in complexity which consists of taking into account friction or air resistance affects the movement of the simulated objects on the screen and consequently the fidelity of the representation.

Manipulation of the complexity variable could also lead from a covert way of showing the model, where primarily input variables and output states are shown (de Hoog, 1991), (notion of the simulation as a black box), to an overt presentation of the model to the learner, where parts of properties of the model (or the model as a whole) as they exist in the machine are shown to her.

4.5. Coordinates of reality or the simulation map

In the light of this framework the simulations of Chapter Two were placed in this fidelity complexity space (Fig. 4.3).

Puckland represented an environment of low fidelity, though images of the two 2-dimensional schematically drawn pucks could probably create the illusion of a realistic representation. The underlying model in this case was simple, since the motion of the pucks would be governed by the masses and velocities of the pucks. These speeds had

just an x component because the pucks moved only in the x direction (linear collisions).

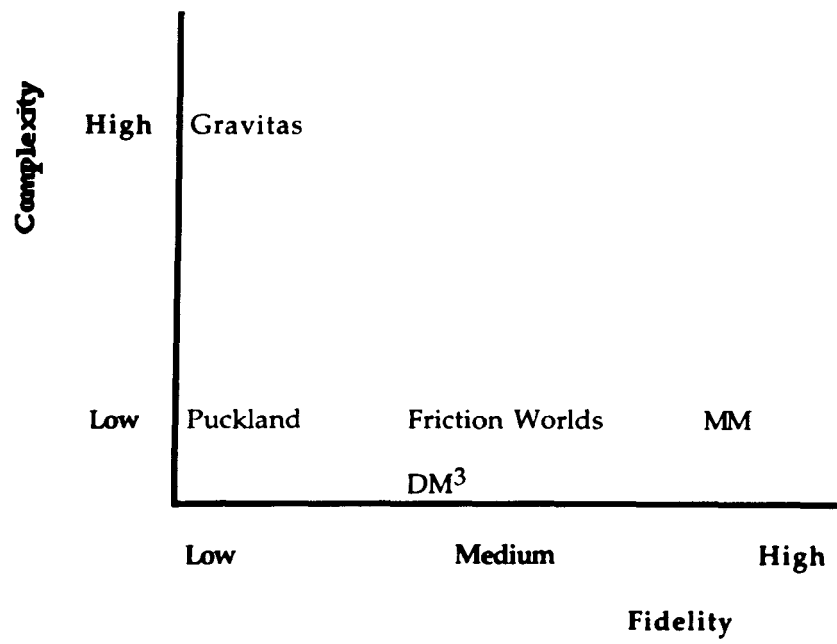


Fig. 4.3. Simulations of Chapter Two on the Fidelity Complexity space.

Gravitas represented a low fidelity simulation (schematic circles moving on the computer screen, representing the planets), whose time fidelity was low as well (in most cases examined, the user had to increase the step in order to observe fast responses of the motion of the MassObs of her choices). But the complexity of Gravitas depended directly on the number of objects which the user decided to include in space. For instance, the inclusion of more MassObs would not affect the system fidelity but would increase its complexity, as the variables and the equations governing the system’s behaviour would also increase.

Friction worlds was of medium fidelity: non ambiguous representation, whose realistic drawn animated objects did not conform in all cases (the alternate realities of the different planets, lack

of gravity everywhere on the screen except in the chute, disappearance of blocks) to the motion in real phenomena. The mathematical equations model represented a low complexity system.

DM³ was of medium fidelity (a two dimensional non ambiguous environment created by the illusion of two dimensional drawn objects moving in space, with the illusion of 3 dimensions given by the background). The underlying model consisted of mathematical equations which corresponded to simple Newtonian formalisms.

MM represented a high fidelity environment whose non ambiguous realistic animated objects conformed to the motion of real phenomena and whose time fidelity was high as well. It is of variable complexity e.g. the linear collisions sequences are low complexity, since the outcome of the collision is determined only by the minimum number of four variables: masses and x velocities of the colliding objects.

| Fidelity considerations | Puckland | Gravitas | Friction Worlds | DM ³ | MM |
|---------------------------|----------|----------|-----------------|-----------------|----|
| Realism of representation | √ | √ | | | √ |
| Non Ambiguity | | | √ | √ | √ |
| Time fidelity | √ | | √ | √ | √ |

Table 4.3. Simulations of Chapter Two checked against the fidelity definition.

The next step was to set the above fidelity-complexity framework to the test. In a case study, educators and software designers who had an

experience with simulations were interviewed, and were asked to evaluate the interfaces and discuss whether they found fidelity and complexity helpful in considering simulations.

4.6. Interviews

This section is the result of a series of interviews on simulations with ten people involved either in the design and implementation of simulations, or using simulations for teaching, either in the classroom or for research purposes. Their experience ranged from the design, development and evaluation of simulations to the use of simulations with students in empirical studies. In two cases, the participants had experience of both implementing and using their own simulations in the classroom.

The participants answered a written questionnaire or participated in interviews, where the original skeleton of the questions was followed. Five of the subjects answered the questionnaire after a session during which they had the opportunity to interact with two simulations and physics related software (Table 4.4).

| | |
|---|----------------|
| Interviews | 5 participants |
| Questionnaires and interaction with two simulations | 5 participants |

Table 4.4. Case study (educators and software designers).

The interviews had the form of discussions based on the following questions:

- What experience do you have of using simulations for teaching?
- What design features make a good simulation?
- Do you have any opinion about how realistic simulations ought to be?
- Is there any literature that you go to, when you want to design a simulation?
- Is there a specific simulation that you consider successful? Why?
- Are high fidelity levels in simulations interfaces necessary for understanding the processes involved?
- How transparent does the learner interface have to be in order to permit a view of the underlying model? (or Can complex and realistic simulations permit the identification of the underlying model?)
- Is the level of fidelity dependent on the knowledge level of the learner?
- Is time fidelity (real time) significant for computer simulations?
- Is the level of motivation enhanced by a high fidelity level?
- Can the learner be helped by shifting fidelity levels during a simulation or a sequence of simulations?
- Is 'hands on' instruction with real equipment or an interactive video the highest degree of fidelity?
- Is there any relation between fidelity and the domain of a simulation?
- Would combinations of the two variables (e.g. low fidelity-high complexity etc.) be beneficial for the learner?

4.6.1. Design features of a successful simulation: clarity and ease of use

Of all the features that the participants considered important, the **interface** seemed to be the most frequently mentioned. They referred to a *“simple and clear interface”* (Ch4-IT, 7, p3), with a *“good graphical output”* (Ch4-IT, 9, p3), *“good graphics, showing relevant, important points”* (Ch4-IT, 10, p4); they pointed out that the interface *“should show something that can’t be seen easily in the lab and it should help students to visualise.”* (Ch4-IT, 7, p3).

The second most important requirement was related to **ease of use**. A simulation should be easy to use and would allow easy user interaction and *“simplicity of operation”*. It should also be *“engaging”* (Ch4-IT, 2, p3) to the users and not confusing.

Among the other significant features which they considered desirable for a successful design were:

- attributes related to the “behaviour” of the interface, such as consistent behaviour and smooth motion of the animated objects in simulations which involve animation and speed
- design considerations relating to the underlying model such as, making the student believe that the presented mathematical model is correct, not erratic, mapping to the everyday real world and the introduction of “cleaned up” versions of the simulated phenomenon, in cases where the real phenomenon is very complicated in terms of the mathematical model.

They also thought that it would be useful if the simulation:

- could quickly manipulate the data and convert them into graphs or tables.
- kept a record of the previous interactions and kept “scores” for attempts (especially for problem solving).
- used such strategies as unexpected variables and provided information about the decisions and paths the learner has taken for motivation and feedback.
- had extensive range functionality.
- could provide something in addition to what simple experiments can achieve.

4.6.2. Degree of realism in a simulation.

It was agreed by the majority of the users (8 out of 10) that there cannot be a general rule on how realistic simulations have to be. The consensus was that this is dependent on the learner level and the goals associated with the use of the simulation, for instance an interviewee commented on the appropriateness of “unreal environments” for young children: *“simulations which are more like microworlds, which use unreal environments like fairy tales or space analogies and can be very effective for young children”* (Ch4-IT, 6, p4).

Another example of such a comment on presenting complex environments to novices was: *“the use of highly realistic simulations for adults can be fairly complex in early learning, where there are many variables to keep track of (such as in Flight Simulators), which I believe can actually interfere with one’s ability to build an appropriate*

mental model of the processes and relationships interacting in the simulation" (Ch4-IT, 4, p4).

As another participant explained, the goals are related to what is taught, since the simulation aims to guide learners towards the correct use of a representational language. He concluded that since the teaching of science has to do with guiding students towards *"a kind of discourse and the correct use of symbolic representations"* (Ch4-IT, 3, p4), the question of realism could be considered *"almost irrelevant"*.

4.6.3. Simulations' bibliography, choice of successful simulations

The participants were asked if they frequently used any reference items of bibliography or guide-lines on how to design a simulation. The instructional design principles which they used were usually based on practice and feedback. Someone indicated the importance of using gaming techniques to engage the learner. The emphasis was on designing the simulation to be used as part of an instructional cycle. The model of such an instructional cycle they had in mind was predict-observe-explain. As one commented, *"You have to make predictions and compare the outcomes with those predictions. You have to record these predictions, pedagogical issues really"* (Ch4-IT, 3, p3).

When asked to choose a simulation, among the ones they had used, which they considered successful, their criteria included: motivation functionality, and user control. They indicated a preference for simulations which were not *"static"* (Ch4-IT, 5, p6), were a

combination of a simulation and a game and which gave feedback to the user.

Half of the participants, as well as taking part in the interviews were available to interact with two simulations. They were asked to choose between their interfaces and provide explanations for their preferences. The interfaces were: one of a simulation implemented using Interactive Physics (IP), a piece of software used for the design and implementation of interactive simulations, and ColaCollision (CoC), an adaptation of a DM³ scenario, Fig. 4.4, (see 5.2.1).

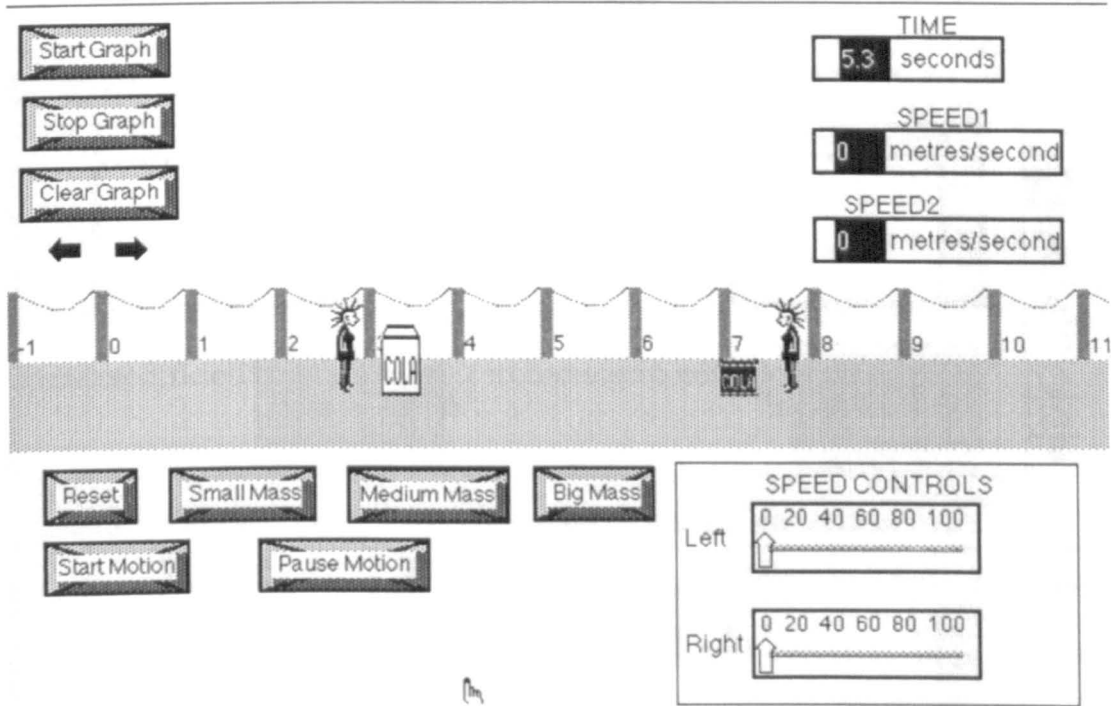


Fig. 4.4. ColaCollision.

Most of the users (4 out of 5) showed a preference for the IP simulation (Fig. 4.5). They thought that there were distracting features in CoC, irrelevant to the simulation, like the “poles and fence in the background”. They also thought that the IP simulation was “clearer” than CoC because it had attributes that contributed to the

understanding of the underlying model (*"it shows the size of forces"*). As a participant commented: *"IP is more focused on the objects which collide. Methods of user interaction are clearer"*.

Another participant explained that the choice between the two would depend on the end users, commenting that CoC would be more appropriate for younger children *"as less abstract representation and qualitative descriptors are used"*. This choice indicated that, according to the interviewees, IP carried in its interface design too much extraneous information, making it less easy for the user to focus on the desired content.

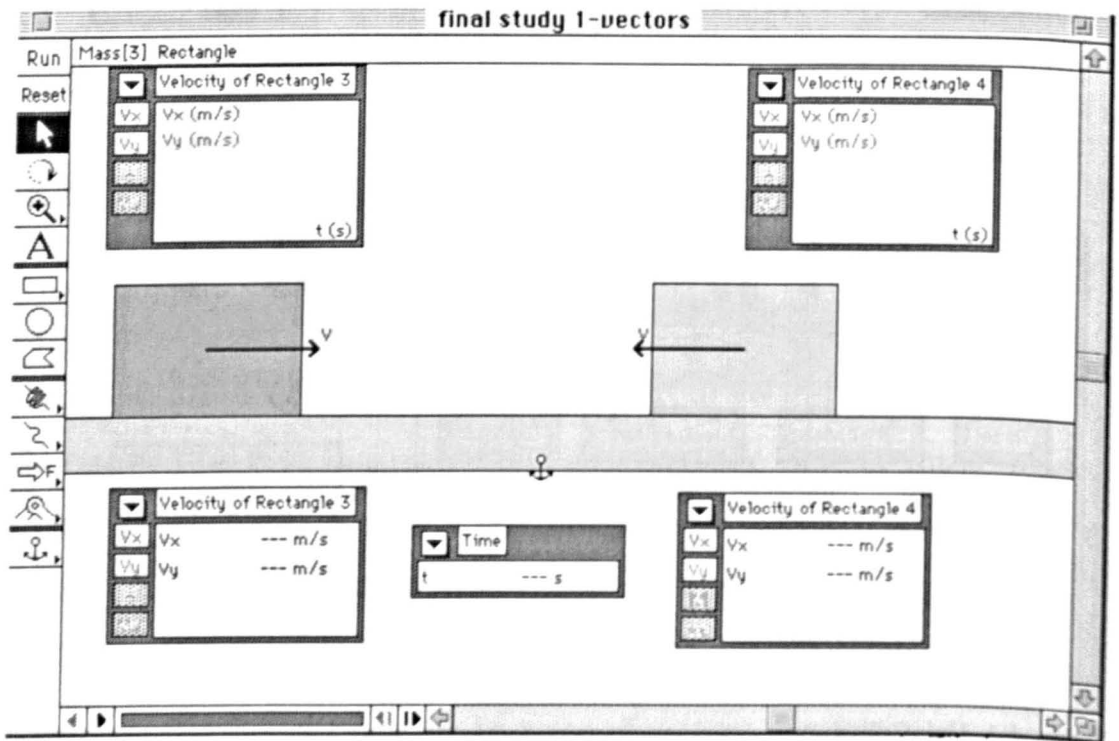


Fig. 4.5. An Interactive Physics (IP) simulation.

4.6.4. High fidelity interfaces and student understanding

The response to the question of whether high fidelity levels in simulation interfaces are necessary for understanding the processes

involved was that high fidelity interfaces can be used to make the simulation look similar to the simulated environment. They can also be used to encourage novice learners *“to feel happy”* (Ch4-IT, 10, p7), and to make students feel *“at home”*, but they are not absolutely necessary.

Two of the participants believed that high fidelity may distract from the pedagogic aim. One of them commented that high fidelity may undermine what educationalists and software designers attempt to achieve with simulations, which was *“to drop people from this rich context to isolate the things that you think are important when you move from the real life version to the physics version by abstracting key features”* (Ch4-IT, 7, p7).

Regarding the relationship between fidelity and complexity, 2 of the participants thought that the relationship is or ought to be linear: increased fidelity would result in increased complexity.

4.6.5. The “transparent” interface and the underlying model

The response to whether visually faithful and realistic simulations hinder the identification of the underlying model was mixed. Commenting on the issue of interface transparency, a participant argued that an interface should be functional rather than just being transparent. An example of another similar comment was, *“Transparency in interfaces is really a different issue altogether in my mind, where I want to see interfaces which do not hinder the use of a system, but I don't see transparency as ‘hiding’ something from the learner”* (Ch4-IT, 7, p8).

One participant stressed the importance of the underlying model in facilitating the students' understanding of the simulated phenomenon. He explained that *"the interface is a mirror of the underlying model, it is the behaviour of the simulation which provides the understanding of the underlying model in most cases."* (Ch4-IT, 9, p8).

One of the attitudes towards complexity was that it is mainly determined by the learner level. An example of a comment of this type was: *"If you send a rocket to the moon you will use relativity theory only at a higher level, you won't use it with primary school children. So the complexity will be determined by the pedagogy not by anything else"* (Ch4-IT, 3, p8). In general though they considered the issue of different degrees of complexity in the underlying model interesting enough to be the object of an empirical study.

4.6.6. Fidelity and the knowledge level of the learner

When asked whether fidelity should be dependent on the knowledge level of the learner, the participants' response varied. Some expressed the opinion that fidelity is also dependent on the level of the learners and it should increase with the learner's competency. The general pattern in three responses was: low fidelity for novice students, high fidelity for experienced students. An example of this type of comment was: *"I believe fidelity should progress as the learner progresses with the model of the simulation. This is pretty standard simple-to-complex stuff."* (Ch4-IT, 1, p8). Others believed that this was a pedagogy-related issue, not an age dependent attribute.

4.6.7. Time fidelity in simulations

The participants' response to "time fidelity" and the use of real time in simulations was that time fidelity is not compatible with real cases when long processes are simulated (e.g. motion in space). In these cases speeding up the time to allow the viewing of a slow process is more than necessary and this was considered to be a big advantage of simulations in relation to similar experiments in the laboratory. However, there was reference to cases where real time contributes to the perception of reality of the user. One example of such a comment was: *"Having real-time experiences with simulations is part of the building of a correct mental model of temporal relation"* (Ch4-IT, 2, p9).

4.6.8. High fidelity and motivation

Not all of the participants thought that motivation is enhanced by a high fidelity level. The distinction they made was between advanced learners, where the high fidelity level might enhance motivation and learners who, not being ready to deal with such high level of visual "complexity", might be demotivated. As someone commented, a possible advantage of high fidelity is that it contributes to *"some sort of contextualisation"*, therefore it is motivating, by *"linking students, showing them the relevance"* (Ch4-IT, 3, p9).

They also isolated those aspects of the interface design which they thought can enhance motivation, giving specific examples of simulations they had used. An example of such a comment concerned

Friction Worlds (described in Chapter Two), which described as a high fidelity simulation: *“in Friction Worlds we have a high fidelity interface, Hoovers that come out and do things. I don’t think this kind of fidelity helps them to understand the concepts very much, it’s only motivational”* (Ch4-IT, 7, p9).

4.6.9. Shifting levels of fidelity and complexity

In response to the question of whether the learner can be helped by shifting fidelity levels during a simulation or a sequence of simulations, the majority of the participants (7 out of 10) thought that presenting the user with different views of the underlying model might be beneficial. As one commented, particularly in physics, *“to move from high fidelity to low fidelity can be helpful, since you want to teach the correct representation systems, diagrams etc.”* (Ch4-IT, 3, p10).

A number of cases were mentioned when it is advantageous to have shifting levels of fidelity:

- in physics, where students using simulations must move from the every day life version to the physics theory version by abstracting key features. As someone commented: *“what you want to end up with is a formalism down to the abstract entities, mass, the distance. You want to draw learners from the high fidelity stuff to the high complexity one”* (Ch4-IT, 4, p10).
- when teaching a concept in a way that it transfers to everyday context. In many simulations the attempt is to bridge the everyday context to the abstract theory.

- when moving from the perceptions of the learner in the subject area upwards to the version of reality which has to be taught.

Other interesting comments that they made on shifting fidelity were:

“progressive levels of realism might also provide different views of a model (i.e. functional, descriptive) and could be of benefit in learning” (Ch4-IT, 2, p10), and,

“it is sometimes appropriate to present different kinds of worlds to allow learners to interact with processes which you want them to generalise to other worlds ” (Ch4-IT, 9, p10).

As someone commented however, a shortcoming of the above arguments is when the underlying model is too abstract and it is difficult to find equivalent representations in everyday context, providing simplistic instead of simple representations: *“You cannot find an everyday context in quantum theory. You cannot really move from every day events to the underlying quantum theory”* (Ch4-IT, 4, p10).

Finally, someone argued that shifting levels of fidelity during a simulation, rather than in a sequence of similar simulations, would probably be confusing for the users, but again this would possibly depend on the level of the students and their previous experience.

4.6.10. Fidelity and “hands on” instruction

In answer to the question of whether “hands on” instruction with real equipment or an interactive video can be thought as the highest

degree of fidelity, 6 interviewees agreed that real equipment has a high degree of fidelity. However, someone else commented, *“even an experiment or setting is an abstraction, an idealisation, a simulation of a real phenomenon”* (Ch4-IT, 8, p11).

4.6.11. Relation between fidelity and the domain

It was agreed that it would be difficult to attribute specific degrees of fidelity to particular domains, i.e. if certain domains could benefit from a degree of fidelity. As one participant commented, quite a few categories of simulations, such as situational or role-playing are not domain-specific, nor are process simulations. Another participant expressed the opinion that the teaching aim was more important: *“I am more comfortable with considering how different goals and audiences for whom the simulations are intended affect the fidelity. I wouldn't think that whether a domain is chemistry or biology somehow determines the required fidelity.”* (Ch4-IT, 3, p11).

4.6.12. What combination of fidelity and complexity

The interviews raised a number of questions and related issues:

- How separate are the variables fidelity and complexity: are they related at all? If so, are they closely linked? They are to a certain degree overlapping issues.
- Fidelity and complexity are both interacting continuums, where it would be interesting to attempt to locate various successful simulations.
- Are “clean” interactions such as high fidelity and low complexity combinations easy to define?

- Many of the questions asked were interesting research topics on their own, so the scope of this research was probably too wide.
- A criticism of the fidelity-complexity approach to simulations was that the design sometimes depends on the expectations of the students and the real pedagogical aim given a particular group of students. Another approach would be designing a simulation for that, rather than focusing on the abstract principles for designing simulations.

4.7. Conclusion

This chapter presented an overview of fidelity theories. A framework was then considered which was derived from these fidelity theories and proved useful for classifying simulations. Finally, a series of interviews with educators and designers discussed fidelity and complexity and their relevance to the design of computer simulations.

The participants of the study accepted that fidelity and complexity represent a useful framework for classifying computer simulations. This classification would potentially be an answer in physics to the problem of finding an effective way of describing the combination of the observable and the Newtonian world in a simulation's design. Their reactions to fidelity implied that the level which helps the users to separate significant from non-significant display features should be investigated. They viewed complexity as dependent on the learner level. Their main objection to the fidelity/complexity framework was that one should be wary in applying any set of abstract principles to designing simulations.

The next step was to use a simulation in order to test this framework, together with a suitable methodology. The following chapter describes observations of users interacting with a specially designed computer simulation called ColaCollision. It was designed to represent a combination of fidelity and complexity: medium fidelity in the visual representation of animated two dimensional objects and low complexity of the underlying model.

Chapter Five

The ColaCollision study

5.1. Introduction

Chapter Three described observations with two interactive learning environments, putting an emphasis on the interface and underlying model as simulation descriptors, while Chapter Four introduced a framework for classifying simulations by the use of two variables, fidelity and complexity. In this chapter observations are described of learners using ColaCollision (CoC), a specially designed computer simulation. The aim was to test a methodology with a simulation which could be described by the use of the fidelity/complexity framework. Issues like testing and choice of an appropriate instructional cycle (Chapter Two), combinations of appropriate worksheet tasks for this kind of interaction (Chapter Three), further investigation of a collaborative schema which would elicit constructive negotiations from the users, while they interacted with the simulation, were investigated.

A description of the structure of the study (subjects, software used, procedure) is followed by observations of participants using CoC. The findings are given and discussed as suggestions for a methodology which would extract suitable data for this research, and would also combine quantitative and qualitative data analysis.

5.2. The Study

The study was set up to investigate the use of an interactive learning environment such as ColaCollision. A teaching aim of the use of the CoC simulation was to help participants visualise instances of collisions.

The pilot study indicated that pairing of participants was more fruitful in encouraging talk than using individuals. The use of a structured worksheet with specific problem activities was considered necessary as a result also of the pilot study. The idea was to observe students working in pairs, this time with the use of a structured worksheet.

5.2.1. The CoC software

ColaCollision (CoC) is based on the DM³ (Direct Manipulation of Mechanical Microworlds) scenarios used in the Conceptual Change in Science project which were successful in eliciting successful explanations from the users (Draper *et al*, 1992).

A set of specification requirements for CoC (Fig. 5.1) was produced by the researcher and this design was implemented by Yibing Li. The idea behind its development was to take advantage of all the characteristics of the DM³ scenarios: dynamic graphing facility, animated objects as realistic-looking drawings, digital counters and graphs of velocity. Its interface could potentially relate to the learner experience without perplexing the user.

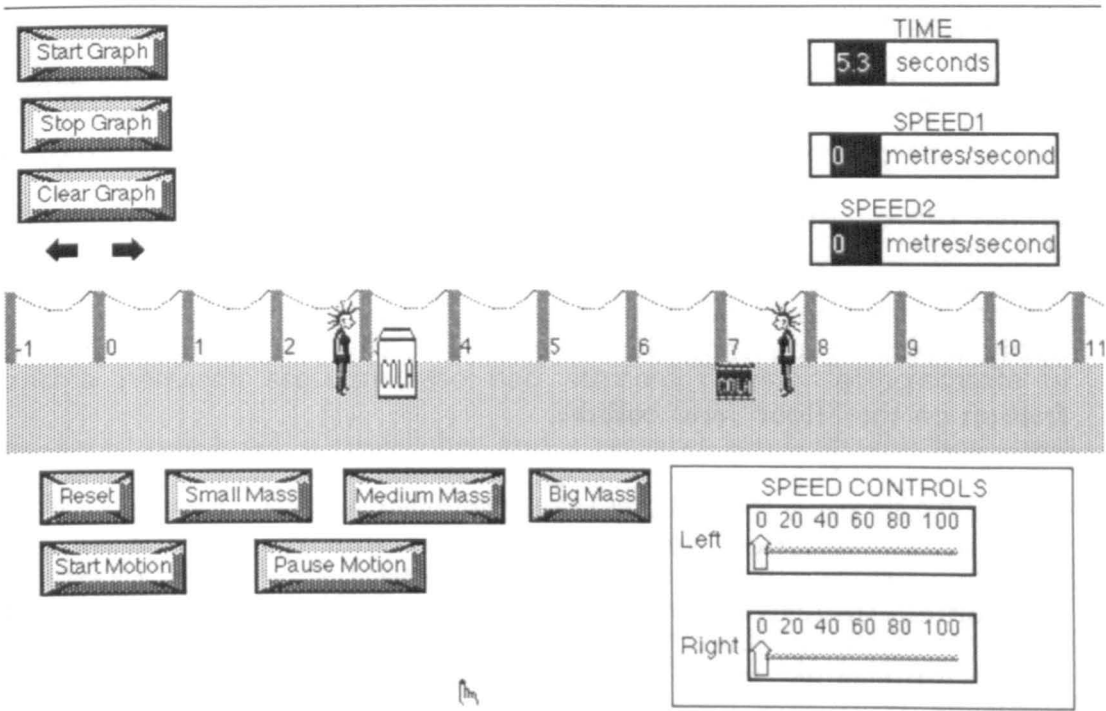


Fig. 5.1. ColaCollision: interface.

CoC simulates motion under forces, allowing users to observe the behaviour of two boxes of Cola after collision. The interface consists of a hybrid screen where the representation of the real world is combined with counters showing the speed of the boxes at any time during the runtime of the simulation. There is also a time counter and control buttons which can start and pause the motion or reset the system, and which allow the user to alter the values of variables. Three variables can be altered: speeds of the two boxes, (from 0 to 100m/sec) and the mass of one of the boxes. This mass can only get distinct values, named Small Mass, Medium Mass (10 times heavier than the Small Mass) and Big Mass (20 times heavier than the Small Mass). There is also a graph facility, where the user can observe synchronous graphs of the speed of the boxes, controlled by three buttons called Start Graph, Stop Graph and Clear Graph.

The representation on the screen consists of an animated sequence, involving 2-dimensional drawn objects moving in space. The fence behind the pushers together with the “floor”, on which the animation takes place, gives the user the illusion of a 3-dimensional environment. At the press of the Start Motion button two persons apply forces by pushing the boxes which afterwards move without friction on the “floor” and collide.

CoC's characteristics were designed for this research: a simple Newtonian underlying model and an interface whose animated objects represented an emulated type of image in the Whalley (1995) taxonomy (4.4.1). It is of medium fidelity: the representation of the animated objects is realistic (animated realistic drawings), without any ambiguity. The use of images relevant to every day life (people dressed as punks, boxes of Cola) enhance fidelity, increasing the relevance of the interface to the users. CoC also uses real time in terms of time fidelity.

CoC was considered to be of low complexity since it is a linear collision whose underlying model consisted of simple mathematical equations and four distinct variables: masses and x-velocities of the colliding objects.

5.2.2. Subjects and procedure

Eight users formed both single sex and mixed gender dyads, as Table 5.1. shows:

| | |
|----------------------|--------------------|
| Single sex dyads: 2, | Female: 1, Male: 1 |
| Mixed dyads: 2 | |

Table 5.1. Gender distribution in participants’ pairs.

The participants were a heterogeneous group in terms of expertise in physics (at least in terms of qualifications): three university lecturers and a research student who had studied physics at graduate or postgraduate level, a researcher and a research student who had done A level physics and two research students who had done GCSE Science in school. They were taken to a room where a Macintosh computer was set up. Data were collected by observing the users interacting with CoC. The users’ interaction was video-taped and their protocols transcribed.

The participants worked for two hours:

- (i) answering a questionnaire and pre test
- (ii) interacting with the simulation.
- (iii) repeating the pre-interaction questionnaire.

In the pre questionnaire they were asked about their experience with computers, their previous knowledge on the nature of computer simulations and their physics knowledge. The rest of the questionnaire asked the participants to make predictions about the behaviour of masses after collision in three cases. These prediction questions are described in detail in 5.3.1.

5.2.3. Description of the worksheet: the task

As part of the interaction the participants were given some initial time to familiarise themselves with the various buttons, controls and displays. They were given a worksheet and asked to carry out three tasks. These tasks were adapted from similar tasks used by Whitelock *et al* (1993b), see Appendix 1, p10.

- Plan and carry out an experiment which could show in ColaCollision the conservation of momentum. Carry out this experiment using ColaCollision.
- If you want to send the boxes travelling away from each other at the same speed, what initial conditions are needed: what masses of boxes must we use, what initial speed (if any) must the boxes have?
- If you want to make one box stop after impact what initial conditions are needed: what masses of boxes must we use, what initial speed (if any) must the boxes have?

Table 5.2 shows the time the users needed to carry out the tasks:

| | |
|----------------|---------|
| Derek-Vanessa | 70 mins |
| Harry-Mick | 59 mins |
| Elisa- Sara | 45 mins |
| Pete- Janet | 50 mins |
| Average | 56 mins |

Table 5. 2. Time taken for CoC interactions.

5.3. Data analysis

5.3.1. Questionnaire analysis

Previous experience with computers

The first question of the pre test questionnaire was about their experience with computers. The range of the participants’ previous experience with computers is given in the table below (Table 5.3):

| | |
|--------------------------------------|----------|
| Word processing, spreadsheets | 8 or 88% |
| Multimedia | 6 or 75% |
| Other (e.g. games, programming etc.) | 5 or 63% |
| No previous experience | 0 |

Table 5.3. Previous experience with computers.

Previous knowledge of simulations

All participants had used a simulation before.

Pre and post test comparison outcomes

In the last part of the pre test questionnaire participants were asked to answer a question on the meaning of conservation laws:

- What is meant by a conservation law? Can you give any further examples of conservation laws?

Then the participants’ initial knowledge on collisions was tested. The subjects were pretested with a questionnaire which was based on

Whitelock *et al* (1993a). They were asked to predict the subsequent motion of two masses after collision for the following 3 conditions:

Condition 1: If you have two equal masses moving at the same speed and colliding (Fig. 5.2) what will happen after the collision?



Fig. 5.2. Condition 1.

Condition 2: If a small mass collides with a much bigger immobile mass (Fig. 5.3) what will happen after the collision?



Fig. 5.3. Condition 2.

Condition 3: If a big mass collides with a small immobile mass (Fig. 5.4) what will happen after the collision?

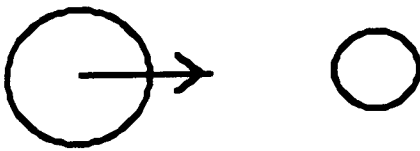


Fig. 5.4. Condition 3.

In the post test all three questions were repeated. A comprehensive table of all the participating participants' pre and post test predictions assessment follows (Table 5.4):

| | Prediction 1 | | Prediction 2 | | Prediction 3 | |
|--------------|--------------|---------|--------------|---------|--------------|---------|
| | Pre | Post | Pre | Post | Pre | Post |
| Vanessa, P10 | Wrong | Correct | Correct | Correct | Correct | Correct |
| Derek, P11 | Correct | Correct | Wrong | Correct | Wrong | Correct |
| Harry, P12 | Correct | Correct | Correct | Correct | Wrong | Correct |
| Mick, P13 | Wrong | Correct | Wrong | Correct | Wrong | Wrong |
| Elisa, P14 | Wrong | Wrong | Wrong | Wrong | Correct | Wrong |
| Sara, P15 | Correct | Correct | Correct | Correct | Correct | Correct |
| Pete, P16 | Wrong | Correct | Wrong | Correct | Wrong | Correct |
| Janet, P17 | Correct | Correct | Correct | Correct | Correct | Correct |

Table 5.4. CoC pre to post test shift.

The comparison between the pre and post interaction tests indicated that there was a shift in the participants’ understanding. The percentage scores of the pre test and post test answers are shown in Table 5.5 and Fig 5.5:

| CoC | Prediction 1 | Prediction 2 | Prediction 3 |
|-----------|--------------|--------------|--------------|
| Pre test | 50% | 50% | 50% |
| Post test | 88% | 88% | 75% |

Table 5.5. CoC, Pre and Post test: Percentage of correct answers.

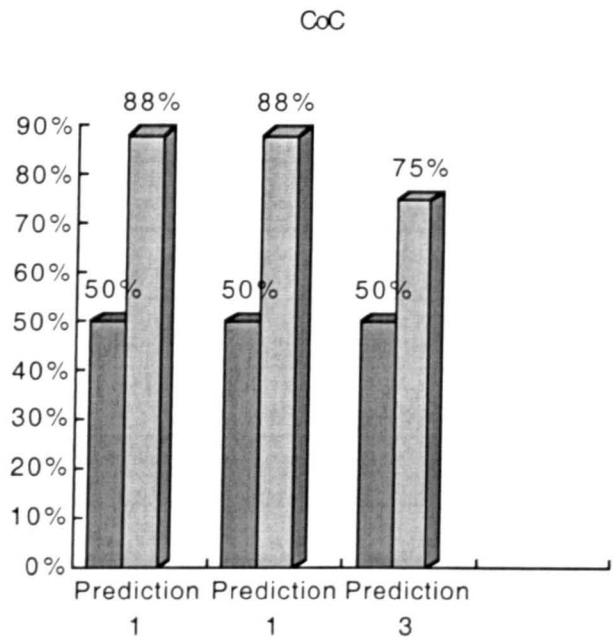


Fig. 5.5. Pre to post test percentages of correct answers.

A one-tailed Wilcoxon signed-ranked test was carried out to see if there was a significant difference between the pre and post test means of the total predictions scores. The result of the Wilcoxon test (Table 5.6) showed that there was a significant difference between the pre and post test total prediction scores ($T=4$; $n=6$, participants with difference score zero are excluded from the analysis; $p<0.05$).

A qualitative analysis of the collected data aimed at assessing how the simulation helped to change people's views on collisions. Three out of the four pairs' interaction transcripts were chosen. The first pair were experts and fared well in the post test. The second pair was heterogeneous in terms of aptitude (two research students, one in physics and one whose expertise in physics was only up to GCSE level), while the third pair could be considered as novices (the expertise of both in physics was only up to GCSE level or equivalent).

| Student | Pre Test | Post Test | Sign of difference | Size of difference | Rank of difference |
|---------|----------|-----------|--------------------|--------------------|--------------------|
| P10 | 2 | 3 | - | 1 | 1.5 |
| P11 | 1 | 3 | - | 2 | 4 |
| P12 | 2 | 3 | - | 1 | 1.5 |
| P13 | 0 | 2 | - | 2 | 4 |
| P14 | 1 | 0 | + | 2 | 4 |
| P15 | 3 | 3 | | 0 | |
| P16 | 0 | 3 | - | 3 | 6 |
| P17 | 3 | 3 | | 0 | |

$\sum_{R=-} = 17$

$\sum_{R+=} = 4$

Table 5.6. Wilcoxon test for CoC .

5.3.2. Discussion of pairs: pre to post gain and interaction

P10, P11: Vanessa and Derek.

| | Prediction 1 | | Prediction 2 | | Prediction 3 | |
|---------------|--------------|---------|--------------|---------|--------------|---------|
| | Pre | Post | Pre | Post | Pre | Post |
| Vanessa, P10. | Wrong | Correct | Correct | Correct | Correct | Correct |
| Derek, P11 | Correct | Correct | Correct | Correct | Wrong | Correct |

Table 5.7. P10, P11: pre to post test shift.

Vanessa and Derek spent some time (Table 5.8) familiarising with the program. They explored the interface and the simulation’s functions. The exploration consisted of running CoC and trying the controls and buttons. As they were not certain if the graph represented momentum or velocity, they devised an experiment of keeping the same speed and varying the masses to resolve this ambiguity (Transcript 5.1).

| Time | Learner activity | Comment |
|-------|--|---|
| 00.00 | Check the simulation's functions (controls and buttons). | Explore the interface. |
| 00.06 | RUN the simulation for demonstration purposes. | Discuss to resolve potential ambiguities of the interface. |
| 00.08 | Devise strategy for dealing with first task. | Plan succession of RUNs with different masses but same initial velocities. |
| 00.11 | RUN. | |
| 00.16 | RUN CoC and calculate sums of momentum before and after. | Satisfied that their results agree with conservation law. |
| 00.21 | RUN for Medium mass, same velocities and calculate total momentum. | Their results agree with conservation law. |
| 00.32 | RUN for Big mass, same velocities and calculate total momentum. | Their results agree with conservation law. |
| 00.45 | RUN the simulation with a variety of ratio of masses. | |
| 01.10 | | Conclude that they cannot reach any acceptable solution because of what they consider to be software inconsistencies. |

Table 5.8. Observation schedule of Vanessa and Derek for ColaCollision.

P11. This must be the small one (points at line on graph), because it changed direction. It went above the dotted line.

P10. It was also the one we chose as having the lower velocity (points at graph). Somewhere it came up 20, so that would do finely with velocity and momentum. So positive direction is the one going this way (right). One way to find out is by having different masses and the same speed. Those look like... We had 40 and 20 and that looks like twice that. We also had different masses. So that would be very much more 40x20 and this would be 20x1. So these must be velocities... It's a measure of velocity. So...

Transcript 5.1.

(CoC, T, P10-P11, p14)

For the first task of carrying out an experiment for demonstrating conservation of momentum, they decided on a succession of

experiments which would demonstrate the law. Their strategy was to keep the initial velocities constant and vary the masses (Transcript 5.2).

- P11. For both objects we can demonstrate, we can go through our three masses for one object... and about speed... And show with the speeds we came up that we have conservation. This is a clue...
- P10. Then we can actually do an experiment in which we can vary the masses.
- P11. Right.
- P10. Keep the speed... We'll still have to multiply them by the masses and then add them. If we add these together, they will be the same.

Transcript 5.2.

(CoC, T, P10-P11, p14)

For the third task they devised a succession of experiments which would demonstrate the law but these were not comprehensive enough to cover a complete set of variable cases. They stopped as Derek was not willing to try other cases, probably because of the time constraints. They were critical of the “behaviour” of the interface, mainly the slow, sometimes erratic response to the clicks of the buttons. They also were of the opinion that the velocity gliders were roughly divided, not allowing a wide range of inputs.

Vanessa and Derek were meticulous in their approach completing the tasks, trying out a comprehensive number of combinations of variable values. They did not manage though with this “trial and error” approach to formulate definitive answers to the tasks, within the time constraints of the interaction.

P12, P13: Harry and Mick

Before they started Harry and Mick discussed the meaning of conservation of momentum and its applications. After running CoC for the first time, Mick needed further explanations on how to calculate momentum from the display of velocities (Transcript 5.3).

| | Prediction 1 | | Prediction 2 | | Prediction 3 | |
|------------|--------------|---------|--------------|---------|--------------|---------|
| | Pre | Post | Pre | Post | Pre | Post |
| Harry, P12 | Correct | Correct | Correct | Correct | Wrong | Correct |
| Mick, P13 | Wrong | Correct | Wrong | Correct | Wrong | Wrong |

Table 5.9. CoC pre to post test shift.

P13. Where is the momentum then?

P12. The masses are both the same and since they are travelling in opposite directions, the total is the difference. And the difference is clearly the same before and after.

Transcript 5.3.

(CoC, T, P12-P13, p18)

Harry suggested an experiment for demonstrating conservation of momentum of varying first the masses (keeping the speeds the same) and then the speeds and calculating total momentum in each case. Mick was doubtful if the outcome would be a value of momentum (Transcript 5.4).

| Time | Learner activity | Comment |
|-------|---|--|
| 00.00 | Discussion about conservation law of momentum. | Harry explains to Mick the meaning of the law. |
| 00.02 | Negotiate what kind of experiment would prove the law. | |
| 00.05 | RUN the simulation. | Familiarise with the functions of the interface. |
| 00.08 | Devise an experiment to run on CoC, RUN. | Negotiate which variable should keep constant and which not. |
| 00.13 | RUN. | They find difficult varying the controls. |
| 00.16 | RUN. | |
| 00.20 | Use pen and paper to calculate sums of momentum Before and after. | |
| 00.24 | Second task, RUN with same masses and velocities. | |
| 00.28 | Discuss appropriate conditions if masses are different. | |
| 00.30 | RUN by varying the speeds. | |
| 00.32 | RUN with different masses. | |
| 00.35 | RUN with different masses. | Try different ratios of velocities while keeping the ratio of masses the same. |
| 00.38 | RUN. | |
| 00.43 | RUN. | |
| 00.49 | RUN. | |
| 00.50 | Discuss appropriate initial conditions for third task. | Do not try them out. |
| 00.52 | Discuss the interface and the simulation's features. | |

Table 5.10. Observation schedule of Harry and Mick for ColaCollision.

P13. But the question was how to prove...

P12. If you change the speed and the mass is the same, and similarly if you go to the medium mass and the big mass, which implies that momentum is conserved.

P13. Right. Consistent. But we are not getting any output for the momentum. We don't actually graph momentum here.

P12. But this is mass in grams.

P13. So because the graph has no scale it actually shows velocity and momentum. What else does it show?

P12. It shows speed.

Transcript 5.4.

(CoC, T, P12-P13, p19)

They ran CoC varying the mass and calculating total momentum in each case. Mick was slower to follow the outcomes of each collision. He was though willing to discuss, e.g. the case when the boxes after the collision moved in the same direction (Transcript 5.5).

P13. That's interesting... So they are both going off the screen at a certain speed, same direction. The large block in the left doesn't change its momentum.

P12. It slows down a bit.

P13. But the small block went off at the same rate.
80m/sec.

Transcript 5.5.

(CoC, T, P12-P13, p19/20)

In the second task they easily found that one correct combination of variables involved having equal masses and equal speeds. However, they considered this case to be a special one, and they discussed the possibility of having different masses and initial velocities (Transcript 5.6).

P12. Well, we want them to travel away at the same speed. The masses are equal, what happens is that the speeds reverse.

P13. So it's two conditions: same initial speed... If the masses are the same and the initial speeds are the same, then the post collision speeds will be the same.

P12. But there are probably other cases when the conditions are different. If one mass is twice the second one.

P13. It will be half the speed then. If the larger mass is twice the smaller mass, if the larger mass is travelling at half the speed, then the post collision speeds will be the same.

P12. Let's try it out.

Transcript 5.6.

(CoC, T, P12-P13, p21)

They spent 30 mins discussing and trying out combinations in order to find the conditions which would satisfy the outcome of the second task in the case of different masses. They correctly introduced conservation of energy in their discussion but did not use it in calculations. They ended up defining one initial condition (masses are equal) and tried out combinations of speed for unequal masses, changing each time the ratio of velocities of the masses. The following shows an instance of their discussion in between runs of the simulation (Transcript 5.7).

P12. You want them to move away at the same speed, it should be at one and a half times that speed.

P13. We have 40, the large is 40, so you need 100... The post collision speed must be the same.

P12. It doesn't work like that. It's actually gone up. It was 73 before... If you have the large mass at 10 and the small mass at 20?

P13. We have 40 and 80. And they left at the same speeds. We have 40 here for the Medium mass left and 80 on the right. And the left with the same speed in the opposite direction... And then we did 60 and then the white one moved away at 73. And then 100 and moved away at 90.

Transcript 5.7.

(CoC, T, P12-P13, p23)

They moved on to the third task where they did not reach a final conclusion on the initial conditions needed. Again they considered

the equal masses and equal velocities condition as a specific case of a more general condition. The following excerpt follows their discussion on the “specific” initial conditions for the third task (immobile mass colliding with equal mass of x-velocity), Transcript 5.8.

P13. It's got to have infinite mass.

P12. If you have one of the masses at zero speed and the same mass coming and hitting. The general case again could be tricky. Let's go for the simple case rather than the general one.

P13. Yeah. I don't want to start the graph. Stop the graph... Same mass. One's got a zero speed and this will be the right one. But it will stand still after the collision... I think if we got longer and we might do more... If these axes were labelled.

Transcript 5.8.

(CoC, T, P12-P13, p24)

They concluded their interaction by discussing the features of the interface and what they considered to be inconsistencies in its design, one of which they agreed was that the graph facility had to be started independently after having started the simulation (Transcript 5.9).

P13. I think there is a problem. When you start motion you get time passing.

P12. And the graph starts before you start motion... The big mass is 20 times the small one, in which case you would expect the height of this to be 20 times the height of that in the graph.

Transcript 5.9.

(CoC, T, P12-P13, p24)

Finally they discussed what they considered to be ambiguities of the interface (Transcript 5.10) and expressed preferences (Transcript 5.11).

P13. Check the velocities of the same mass? Actually do these speed controls set the actual speed of the mass or set the push forces? Are they speed controls?

Transcript 5.10.

(CoC, T, P12-P13, p21)

P12. They could have momentum as well. Well, I think that part of the exercise is to work out momentum.

P13. Labelled. There are things about the interaction here. E.g. stop, start Graph when you feel like it. Stop it before you clear it. And it should tell you what the relationship between the masses is. m , $10m$, $20m$.

Transcript 5.11.

(CoC, T, P12-P13, p24)

They also commented on the realism of the motion of the simulation objects: *"I don't think that it actually travels at 20m/sec across the screen, does it?"*(CoC, T, P12-P13, p24).

They had interesting intuitions about the role of simulations as learning environments which present the learner with instances of phenomena but do not actually teach her directly physical concepts (Transcript 5.12).

P13. Let's see the question again. Design an experiment which shows the conservation of momentum. We assume that we know what momentum is... One of us already knew what the conservation of momentum was so why play around with the idea of finding a way to show the conservation of momentum?... Using this package to learn if you didn't know what the conservation of momentum was.

Transcript 5.12.

(CoC, T, P12-P13, p20)

Mick and Harry were a mismatched couple in terms of domain knowledge but they both had interesting insights on aspects of CoC. Their approach to completing the tasks ignored the conservation laws and resulted in an open ended investigation of a wide range of values of masses and velocities.

P14, P15: Elisa and Sara.

| | Prediction 1 | | Prediction 2 | | Prediction 3 | |
|-------------------|--------------|---------|--------------|---------|--------------|---------|
| | Pre | Post | Pre | Post | Pre | Post |
| Elisa, P14 | Wrong | Wrong | Wrong | Correct | Correct | Wrong |
| Sara, P15 | Correct | Correct | Correct | Correct | Correct | Correct |

Table 5.11. CoC pre to post test shift.

| Time | Learner activity | Comment |
|-------|--|--|
| 00.00 | Discuss about conservation laws. | Sara explains to Elisa conservation of momentum. |
| 00.05 | Negotiate what kind of experiment would prove the law. | |
| 00.08 | RUN the simulation. | |
| 00.11 | Devise an experiment to run on CoC, RUN. | Equal masses and velocities. |
| 00.15 | RUN with non equal masses. | They find it difficult to vary the controls. |
| 00.20 | | Discuss the expression of the conservation law. do not use it with the values of the simulation. |
| 00.22 | | Decide not to spend any time on the second task. Consider obvious that the only conditions possible are equal masses and equal velocities. |
| 00.25 | Third task RUN unequal masses and velocities. | Try to achieve conditions where a big slow moving mass will be stopped by a slower small mass. |
| 00.27 | RUN by varying the speeds. | |
| 00.30 | RUN by varying the speeds. | |
| 00.35 | RUN with different masses and speeds. | Vary the mass to medium and use trial and error for achieving the desired outcome. |
| 00.38 | RUN by varying the speeds. | |
| 00.40 | RUN by varying the speeds. | |
| 00.42 | | Decide to use equal masses, one of them immobile after Sara's suggestion. |
| 00.44 | RUN with the conditions they agreed upon. | |
| 00.45 | | Attempt to explain the outcome. |

Table 5.12. Observation schedule of Elisa and Sara for ColaCollision.

Elisa and Sara spent 45 mins in front of the computer. They started by discussing the meaning of physics concepts involved in the simulation (definition of momentum, meaning of the conservation law), with which Elisa was not familiar (Transcript 5.13).

P14. Momentum has to do with velocity and mass, weight and speed.

P15. Yeah.

P14. In layman's terms... So momentum is a measure of weight and speed (kind of). Before collision and after. Right?

P15. Total momentum before equals total momentum after.

Transcript 5.13.

(CoC, T, P14-P15, p24)

Their experimentation with masses and velocities for the first task (to carry out an experiment which would show the conservation of momentum) did not involve any calculations or verification of their experiments by using the simulation. For the second task of finding initial conditions, they considered it unnecessary to experiment with mass and velocity combinations or even verify it by running the simulation, since they were certain that equal masses and velocities were the only possible initial conditions.

For the third task, after experimenting with variations of masses and velocities, they concluded that the only appropriate initial conditions should be equal masses and the velocity of the second mass should be zero.

They used a correct model to explain their rationale of actions, where motion post collision was explained not only by the mass of the

projectile but the target mass. This rationale however did not take into account the conservation laws. Elisa believed that a big mass which moves slowly could be stopped by another smaller mass having appropriate velocity. They spent some time trying to find a reasonable ratio which would satisfy the large-small mass combination. Sara was of the opinion that the combination of equal masses and zero velocity of one of the masses would constitute one solution to the third task (Transcript 5.14).

P15. We can only do this with equal masses and equal velocities. That's the problem...

P14. You clever thing.

P15. Oh, it's not clever, I know that.

R. How do you know?

P15. Masses are equal, but there is only enough to move one box, and it's moving.

P14. It nicks the energy.

P15. But is it transfer?

R. Is it velocity you are talking about?

P15. I think it is K. E.

Transcript 5.14.

(CoC, T, P14-P15, p29)

Their mention of transfer of energy was not adequate in explaining why they ended up with equal masses and one zero velocity as initial conditions without doing any calculations (Transcript 5.15).

Researcher. You ended up using equal masses. What was your logic behind that?

P14. I thought that a big one would sort it out.

R. What do you think determines the motion of the masses?

P14. It might be too heavy in itself to move. But thinking about it, the little one won't stop it.

P15. You should use correct proportions of mass and velocity. You know the energy. You can make a big mass with little velocity to have equal energy to a small mass with big velocity... but the calculations are too much.

P14. We also had problems with the speed controls.

P15. And you also don't have enough choice for the masses.

Transcript 5.15.

(CoC, T, P14-P15, p29)

During the interaction, they did not use the graphs much. They spent some time in the beginning of the interaction discussing what the graphs of the simulation represented. They also had a brief discussion, while completing task 1, how the motion of the circles corresponded to points on the graph (Transcript 5.16).

P15. They've stopped and they've gone to 0. This must be velocity (on the graphs). They are going in the opposite direction. And below 0 it means it goes backwards.

P14. Right.

Transcript 5.16.

(CoC, T, P14-P15, p25)

Whereas, for tasks 2 and 3 they did not use the graph facility at all (Transcript 5.17).

P14. We don't need the graph now.

P15. No, it wasn't that helpful with the graph, was it?

Transcript 5.17.

(CoC, T, P14-P15, p27)

They were not very happy with the multiple representations in the interface and how it responded to their inputs: the mass controls did not respond promptly, only one of them was variable, corresponding to Small, Medium, Large without being clear what mass values were used, the velocity gliders were not subdivided sufficiently and the graphs were not labelled (Transcript 5.18).

P15. 14.1m/s... The speed stays constant during the motion... Let's decrease it now only a tiny amount.

P14. Can we do that or is it very crude?

P15. There. And the other one will be 40... I don't think you can do that. It can only be 20, 40, 60...

Transcript 5.18.

(CoC, T, P14-P15, p28)

Elisa and Sara worked energetically in front of the computer, rationalising their actions. They used a “trial and error” method of varying velocities and masses to complete the tasks. They did not however make any connection between the conservation laws and the completion of the tasks. It is worth mentioning that Elisa’s third post test prediction was wrong. She correctly predicted in the pre test that the boxes *“will both keep moving after the collision to the right”* (CoC, Q1, P14 p6). In the post test however she used a vague statement in describing the outcome of the collision: *“It depends on velocity and speed of masses that collide”* (CoC, Q1, P14 p6).

5.3.3. Observational data

For all the participants of this study what were considered as inconsistencies of the CoC interface caused dissatisfaction with the

software. They attributed their difficulties in manipulating the controls of the interface to such factors as:

- the controls of the simulations did not always respond promptly
- there was no indication in the interface what the value of the mass of the boxes was
- the velocity gliders were roughly divided and
- the graph facility had to be started independently after starting the simulation with the effect of a delay in starting the graph synchronously.

The participants hardly used the graphs to keep track of the variable values, preferring instead to use the digital velocity counters. The ones that used the graph facility had difficulties in interpreting the graphs.

5.4. Findings of the study

The users in this study exhibited a distinct behaviour, which was similar for “experts” and “novices” while interacting with the simulation. They approached the tasks by using “trial and error” methods, in manipulating the simulation variables. The main drawback of an approach like this was that they negotiated towards the completion of the tasks without taking into account the conservation principles and did not realise the full implications of conservation laws for the behaviour of the masses.

It seems that the nature of the tasks of the study (especially the ones about initial conditions), challenging though they were, encouraged the users to use “trial and error” methods. They did not help the participants enough to move from their semi qualitative statements

on the behaviour of the masses. Those semi qualitative statements did not support scientific explanations of post collision behaviour since they ignored the conservation law explanations.

The users responded positively to the interface of CoC and the simulation made sense to them as a valid substitute of a real experience. As a participant commented: *"Seeing the processes is something that is very difficult to do in real life. Having the visual input allows me to think around it without getting lost"* (CoC, Q2, P17, p12). Most of them appreciated the unambiguous, real life context representation which was thought to be one of its attractive attributes. As another user commented: *"it was nice to see the interface of CoC"* (CoC, Q2, P13, p10). However, the fidelity of the interface was undermined by the unrealistic behaviour of the simulated masses.

The users' satisfaction with the way they performed ranged from positive feedback on their performance to dissatisfaction. Half of the participants (4 out of 8) felt dissatisfied with their performance. Their dissatisfaction was related to what they considered as inconsistencies of the interface, as they thought that the interface did not allow them to apply the problem solving strategies they had in mind.

The majority of the users (6 out of 8) considered the CoC interface to be unfriendly. Its transparency was undermined by the fact that the simulation was *"slow to respond"* (CoC, Q2, P11, P17, p9) and adequate choice was not given in the range of variables. Users commented: *"I couldn't do things I wanted to do because the scales were not enough divided"* (CoC, Q2, P10, p10) and *"The data on the screen were less detailed than other simulations i.e. the mass size, small big and large,*

do not permit easy calculations to be made with accuracy” (CoC, Q2, P16, p11).

They suggested changes, which they thought would increase the effectiveness of the software. For instance, one participant expressed her preference for a more flexible, “customisable” interface: *“It would be better if the user could customise the screen and make choices”* (CoC, Q2, P15, p9). The experience with linear collisions in the simulation was unsatisfactory for another user who commented that a simulation which teaches kinetic energy and momentum *“would be much better in 2-D with conservation of energy where it can seem more surprising with collisions at arbitrary angles”* CoC, IT, P12, p11).

5.5. Conclusion

| |
|--|
| Medium fidelity/low complexity (realistic, non ambiguous interface but difficult to control) |
| Decorative elements (backdrops and illusion of three dimensional motion) make the interface relevant to users’ real world experience |

Table 5.13. Characteristics of ColaCollision.

CoC which was designed for this research had characteristics that made it suitable for this study: it corresponded to a combination of values of fidelity/complexity (medium fidelity/low complexity) and had a non ambiguous interface consisting of simulated objects, with no use of idealisations (Table 5.13).

The domain of the simulation (collisions) proved to be a rich enough area which led to the use of simulations of colliding masses for the

following case studies. The tasks in the worksheet which the participants completed during the interaction engaged the users in trying to find appropriate solutions, but it seems that their open-ended nature did not encourage the use of mathematical descriptions in the application of conservation laws instead of the “naive” predictors the participants used. For the next set of studies, it was decided that a more mathematically oriented set of tasks, of a more quantitative nature should be used instead, to elicit appropriate comments and descriptions from the users. An appropriate set of tasks would potentially help students to move away from qualitative, naive statements and towards quantitative reasoning, incorporating consciously the mathematics of a problem in their thinking.

The real life context representation of the simulation was appreciated by the participants. Multiple representations (digital counters and graphs of velocity) which were part of the interface also encouraged the use of quantitative reasoning. However, the realistic aspect of the interface was not complemented by consistent behaviour of the animated objects. CoC's effectiveness as a learning environment was undermined by the lack of functionality, which made it less valued by the users.

The implications for fidelity and complexity in an interactive learning environment were also discussed. The findings of the study imply that simulation design should take into account the appropriate combination of fidelity and complexity level.

Wilcoxon's test proved to be a suitable test for detecting statistically significant conceptual shifts. Another statistical test, McNemar's

(binomial) was decided to be used as well for the following studies. Its layout (see 7.3.1 and 8.3.1) would also help to identify interesting cases for qualitative analysis of the students' interactions. The aim of this analysis was to find common characteristics of behaviour and attitudes towards the software, to highlight the general style of interaction and allow to examine in detail significant learning episodes.

The outcomes also indicated that there is a need to take into account the user's ideas and opinions about what constitutes an effective simulation. The users of the study had interesting views on what they expected a functional and intuitive interface to be like. This led in the following chapter to an overview of the issue of usability and how it can be applied on educational software. It also led to the need for designing that part of the study which would record the users' ideas and opinions, by the use of interviews and appropriate questionnaires.

The next chapter describes the construction of a set of suitable hypotheses as implications of the fidelity-complexity framework and also the research tools that were considered as appropriate for these hypotheses to be put to the test.

Chapter Six

Design and Methodology

6.1. Introduction

The preliminary studies in Chapter Three and Five looked at the use of simulations in relation to their characteristics (focusing on the interface and underlying model). The literature search combined with the studies’ outcomes identified in Chapter Four a specific area of research: to investigate how the use of two variables as components of the perceived reality of simulations by the students, **fidelity** and **complexity** (Fig. 6.1) could give insight on students’ learning from simulations. The main concern of this thesis is to investigate how these factors can affect students’ learning of the physics concepts.

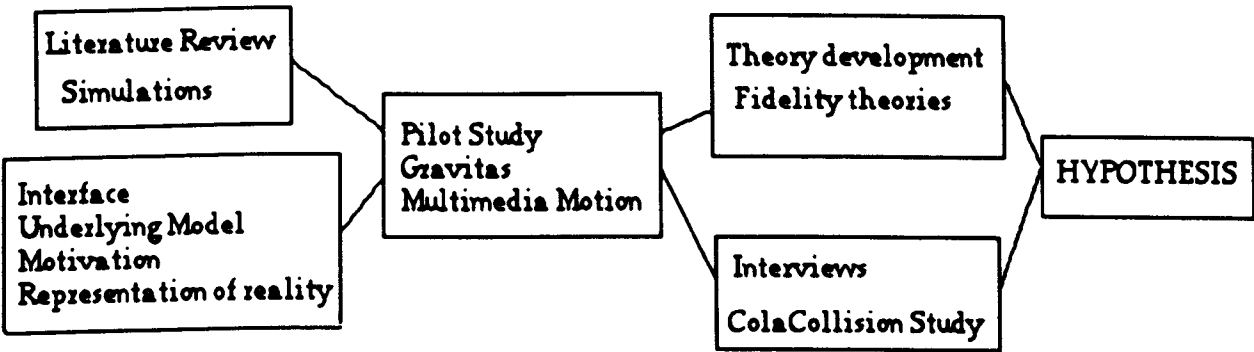


Fig. 6.1. Overview of the research hypothesis development.

In the beginning of this chapter the research hypothesis will be discussed, drawn out as an implication from the fidelity-complexity framework together with a rationale for the research which led to the development of a research hypothesis. It will be followed by a

description of the methods used to collect data in the case studies. The data analysis methods used are described and there is a discussion of the merits of such analysis compared to other methods.

6.2. Research hypothesis

The central idea behind this research is that well designed computer-based simulations can promote learning. The studies were set up to investigate what design issues are essential to the creation of successful simulations. They involved students interacting with a number of simulations and explored the implications for design.

In physics simulations, idealisations of reality are twofold. Firstly the visual representation of the real world can vary from stark realism to pure abstraction. Secondly the user is presented with a model of physical reality, whose similarity to the real world (in terms of the physical laws describing the behaviour of the objects of the simulation) can vary. These variations can make a system more or less complicated, e.g. by changing the forces acting on the system (frictionless or friction-ridden environments), or the dimensions of the space on which the simulation objects move.

As a result of this rationale an overall statement of a research hypothesis is proposed which outlines in a general form the implications of varying fidelity and complexity on students' learning of the domain of the simulation:

Altering the fidelity level of a simulation and the relation between this fidelity and the complexity of the underlying model affects students' learning and contributes to the students' perception of reality.

By varying fidelity and complexity, it can be investigated whether certain combinations of the two variables can make students more comfortable with the abstractions of physics and help them to relate these abstractions to the real world.

The full consequences and implications of this general statement were outside the limits of this research, during the period of study for a PhD. Consequently this overall statement was broken down into three specific statements, which were investigated in a number of small scale case studies. The particular statements referred to high fidelity simulations, to low complexity ones and to the use of multiple representations in the interface's design.

1

Simulations with high fidelity interfaces affect students' learning and contribute to increasing the students' perception of reality.

The physics which is taught in the classroom is based on abstractions and schematic representations of physical reality (points, vectors, abstract drawings). High fidelity simulations, especially the ones where the underlying model is kept simple, can create the appropriate conditions for the users to relate their classroom knowledge to real

situations. They do not overwhelm novices, and facilitate the transfer of learning from the Newtonian world to real situations.

A complementary hypothesis emphasised the importance of low complexity for novice learners:

2

Low complexity simulations provide novice users with the necessary foundations in conceptual learning.

The interface in most simulations contains multiple representations: either digital or graphical indicators of the system's behaviour. In quite a few simulations these indicators follow synchronously the animated action, or can be examined upon demand by the user. The view of this research is that they are important for giving the users the essential knowledge for constructing the set of correct Newtonian formalisms they need for understanding the physical phenomenon. The third complementary hypothesis concerned the effect of the use of multiple representations in user interface design.

3

The use of multiple representations in interface design can enhance students' understanding of the underlying physical model.

To test these hypotheses a number of simulations were used. The aim was for the students to use distinct combinations of the two variables, representing different aspects of fidelity and complexity.

It should be noted that none of the simulations in this work involved students constructing their own models in the computer (Webb, 1994). This is certainly a relevant and interesting area of research in detecting users' perception of the underlying model, but beyond the scope of this thesis.

6.3. Aim and procedure of the studies

The studies mainly consisted of interactions with three simulations. These simulations are different representations of physical reality, simulations of the same physical phenomenon with different degrees of fidelity and complexity. The physical phenomenon is linear collisions: why it was considered appropriate for students' learning about this type of interaction is described in the following section.

These studies were not specifically intended to contrast learning about collisions with a traditional classroom approach, though quite often the point of reference was the learning experience in the classroom or the physics lab. A significant question in educational research has been whether the technology offers greater learning than the same amount of time using non-technological instruction. Reviews of research (e.g. Berger et al, 1994) indicate that interest in this type of research has waned and fewer studies raise the above question. The reason cited for this decline in comparison studies is the fact that technology is now common, so computers from now on will be an integral part of teaching and learning. Secondly, the researcher's view is that partly this decline is due to the difficulty in conducting

comparative studies, e.g. finding a suitable control. Also any standard way of tuition can be enhanced by the use of appropriately designed educational software.

The aim of these studies was to investigate the use of simulations and identify factors which contribute to their successful use by learners. It was also to explore the design of interactive computer simulations and the relationship between the characteristics of the simulation and the evidence of the students' learning of the relevant physics concepts. The intention was to observe students interacting with a computer program and to use these observations to consider how the program helps them as they attempt to construct knowledge, as well as to detect conceptual changes in learners, either from the pre to post test comparisons or from the qualitative analysis of the students' responses.

A teaching aim of using the simulations was to help participants to make accurate predictions of the outcome of colliding masses and to improve their problem-solving skills by visualising instances of collisions. It was also aimed, with the help of the questionnaires and worksheets, to make the students aware of conservation laws (momentum and kinetic energy) and to encourage them to apply these laws to the masses in the learning environments. The studies also investigated how participants who could quote correctly conservation laws were also able to apply and investigate these laws in the computer based simulated labs. The learning outcomes of the students' performance would ideally indicate how effective the learning environments were for instructional purposes.

The technique used was videotaping the output of the computer monitor and at the same time recording the students’ comments. The advantage of using a technique like this is that their interaction can be analysed later in conjunction with the observational records, questionnaires and interviews (Table 6.1).

| PROCEDURE |
|---|
| 1. Users complete pre test questionnaires |
| 2. Interact with simulation in pairs |
| 3. Fill post test questionnaires |
| 4. Participate in one to one interviews |

Table 6.1. Outline of the data collection procedures used in the studies.

The following section (6.3.1) gives an overview of the research in learning about collisions.

6.3.1. Learning about collisions

One area of physics (that involving collisions in mechanics) was chosen. It has been already investigated in the pilot and CoC studies from a more general point of view. The simulations used represented motion of masses during elastic collisions. Research (Stainton-Ellis, O’Shea & Scanlon, 1989; Grimellini-Tommasini et al, 1993) has shown that this is an area which is not well understood by students. Difficulties appear even in the most simple problems about collisions, where rotations can be neglected and only linear momentum and energy conservation laws are necessary (ibid.).

Research on students’ understanding of mechanical collisions differentiates between the students’ spontaneous responses and the

experts' responses which are based on the underlying physics theory and the conservation laws which determine the outcome of collisions. Thus, Grimellini-Tommasini et al (1993) describe the differences between what they define as the spontaneous perspective in describing/interpreting collisions and the disciplinary perspective based upon the energy and linear momentum conservation laws.

An overview of the differences between spontaneous/Aristotelian and disciplinary/Newtonian frameworks for collisions is presented in Table 6.2.

| | Spontaneous | Disciplinary |
|-----------------------|--|--------------------------------------|
| Velocity | Motion implies force. | Motion can take place without force. |
| Acceleration | It is not used to explain motion. | Acceleration implies force. |
| Force | Related to velocity. | Related to acceleration. |
| Momentum | Confused with velocity. | Product of mass and velocity. |
| Kinetic Energy | Depends only on velocity, not on mass. | Modulus of $1/2mv^2$. |

Table 6.2. Comparison of spontaneous and disciplinary frameworks in mechanics.

Categorising the forms of explanations the students prefer when they talk about collisions in the spontaneous framework, Whitelock (1993a) gives two different models used by students to explain the phenomenon: a linear causal model and a resistance/reciprocal causal model:

In the linear causal model, the prime cause and predictor of motion is the mass of the incident mass, whereas the resistance model does not just utilise a primary causal agent to explain motion but also takes into account

the presence of the target mass. The subsequent motion is then thought about in terms of the resistance which can be offered by this second mass. These models... do not produce the correct predictions when conservation of energy is misunderstood. This means that although both models predict a transfer of energy from a moving to a stationary object, they cannot say how much energy/momentum is transferred if the above principle is not understood. This accounts for instance for the incorrect predictions when equal masses collide. Research has shown that the linear causal model is the preferred form of explanation.

(Whitelock et al, 1993a, p6)

Both models represent a spontaneous perspective in describing/ interpreting collisions, which does not take into account the conservation laws in order to predict and explain collisions (Table 6.3).

| COLLISIONS | |
|-------------------------|--------------------------|
| Spontaneous perspective | Disciplinary perspective |
| Linear causal model | Conservation of energy |
| Resistance model | Conservation of momentum |

Table 6.3. Spontaneous and disciplinary perspective in mechanical collisions.

The studies took into account learners’ conceptions and the analysis of the physics domain. The simulations which were used had in their design elements which could potentially ease the students’ transition from the spontaneous perspective (users’ prior conceptions), to the disciplinary one (the physical laws active in them), via the visual, graphical and numerical representations of the collected data.

6.3.2. Choice of simulations

Multimedia Motion (MM)

Multimedia Motion (MM) is a series of CD ROM based sequences (it was described in detail in 2.8.5). MM are data driven, high fidelity simulations based on a combination of video and Newtonian treatment of the underlying physics model (Fig. 6.2).

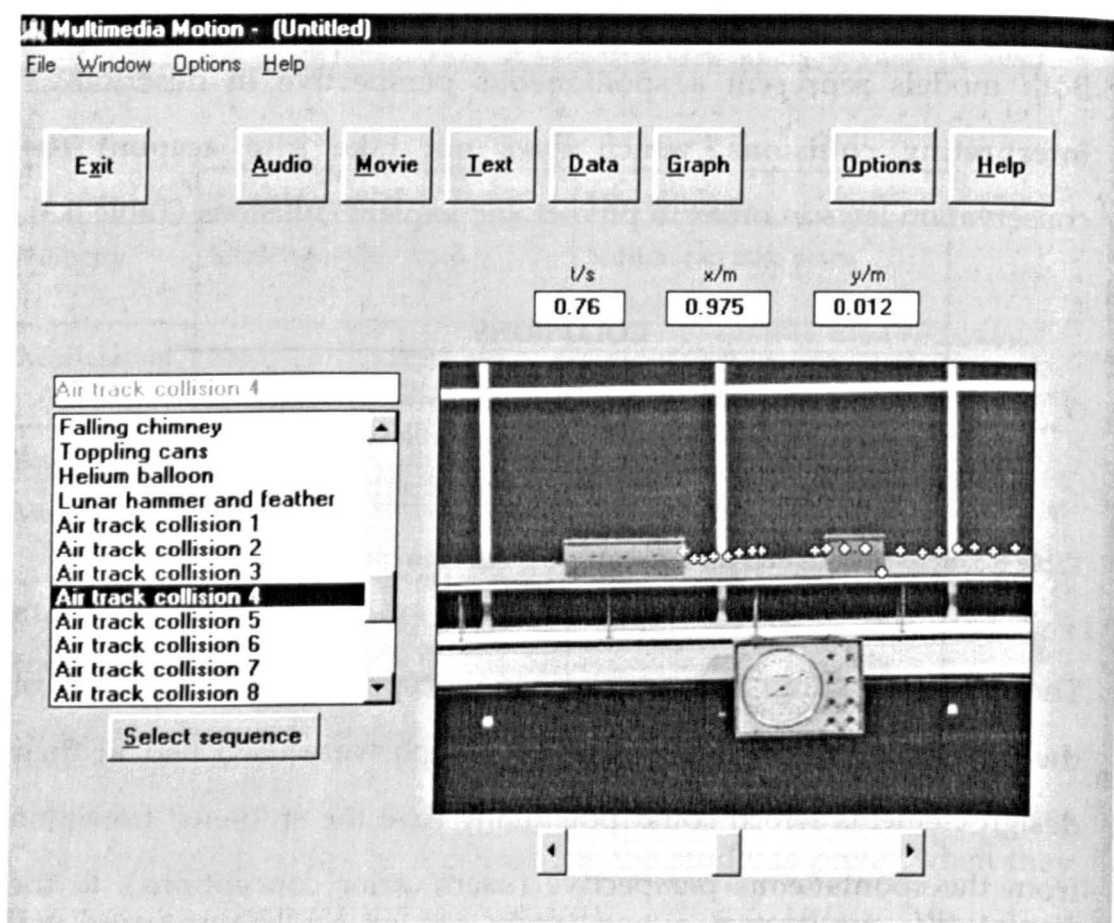


Fig. 6.2. Multimedia Motion: interface.

MM presented characteristics which made it suitable for this research: it has a realistic looking interface and it represented a discrete point in the fidelity complexity grid (see Fig. 4.3, section 4.5). In terms of visual representation it marked a high point in the fidelity axis as video-based simulation with movie-like sequences. Whalley's (1995)

categorisation of image types between “real” and “virtual” (Fig. 6.3) would leave MM situated between the “fragmented” and the “annotated”. By “fragmented”, he (ibid.) denotes the type of image, where a video fragment can be shown as part of the screen to the students. MM though contains elements of another image type, the “annotated”, where “staged animation by the use of overlaid graphic annotation” is presented to the user, in the form of multiple representations, for instance the mouse clicks on the screen as overlaid points, corresponded to the data collected by the users. MM uses real time, in terms of time fidelity.

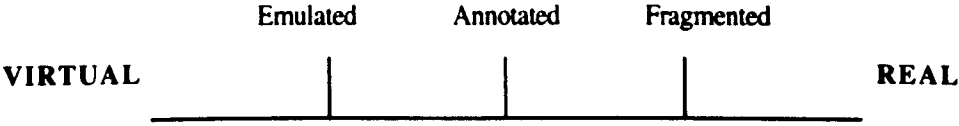


Fig. 6.3. Image types (Whalley, 1995).

It is low complexity since it represents a linear collision. In consequence the outcome of the collision is determined only by the minimum number of four variables: masses and x velocities of the colliding objects.

MM represents a suitable transition from a real world experience to the simple (in terms of physics laws) Newtonian settings of the simulation. It also provides the possibility for the students to examine multiple representations of the collected data, using spreadsheets (Fig 6.4) and graphs of position, acceleration, and velocity (Fig 6.5), thus increasing the possibility of a successful deduction of the relevant physics laws.

| Data - (Untitled) | | | | | | |
|-------------------|-------|-------|--------|--------|---------|--------|
| File Edit | | | | | | |
| Exit Print | | | | | | |
| t/s | x/m | y/m | v(x) | v(y) | a(x) | a(y) |
| 0.000 | 1.238 | 0.564 | | | | |
| 0.040 | 1.190 | 0.557 | -1.095 | 0.000 | | |
| 0.080 | 1.151 | 0.564 | -0.946 | 0.031 | 1.866 | -1.563 |
| 0.120 | 1.115 | 0.561 | -0.946 | -0.125 | 0.000 | -1.953 |
| 0.160 | 1.075 | 0.557 | -0.946 | -0.125 | -1.244 | 1.563 |
| 0.200 | 1.039 | 0.553 | -1.045 | 0.000 | -1.866 | -5.078 |
| 0.240 | 0.991 | 0.557 | -1.095 | -0.531 | 1.244 | 0.781 |
| 0.280 | 0.952 | 0.509 | -0.946 | 0.063 | 1.244 | 14.844 |
| 0.320 | 0.916 | 0.561 | -0.995 | 0.656 | -1.244 | -0.781 |
| 0.360 | 0.872 | 0.561 | -1.045 | 0.000 | 2.488 | -8.984 |
| 0.400 | 0.832 | 0.561 | -0.796 | -0.063 | -8.709 | -0.781 |
| 0.440 | 0.808 | 0.557 | -1.742 | -0.063 | -11.197 | 0.781 |
| 0.480 | 0.693 | 0.557 | -1.692 | 0.000 | 14.307 | 0.000 |
| 0.520 | 0.673 | 0.557 | -0.597 | -0.063 | 13.063 | -1.953 |
| 0.560 | 0.645 | 0.553 | -0.647 | -0.156 | -1.244 | -0.391 |
| 0.600 | 0.621 | 0.545 | -0.697 | -0.094 | -0.622 | 1.172 |
| 0.640 | 0.589 | 0.545 | -0.697 | -0.063 | 2.488 | 0.391 |
| 0.680 | 0.565 | 0.541 | -0.498 | -0.063 | 2.488 | 3.125 |
| 0.720 | 0.549 | 0.541 | -0.498 | 0.188 | | |
| 0.760 | 0.526 | 0.557 | | | | |

Fig. 6.4. Multimedia Motion: spreadsheet.

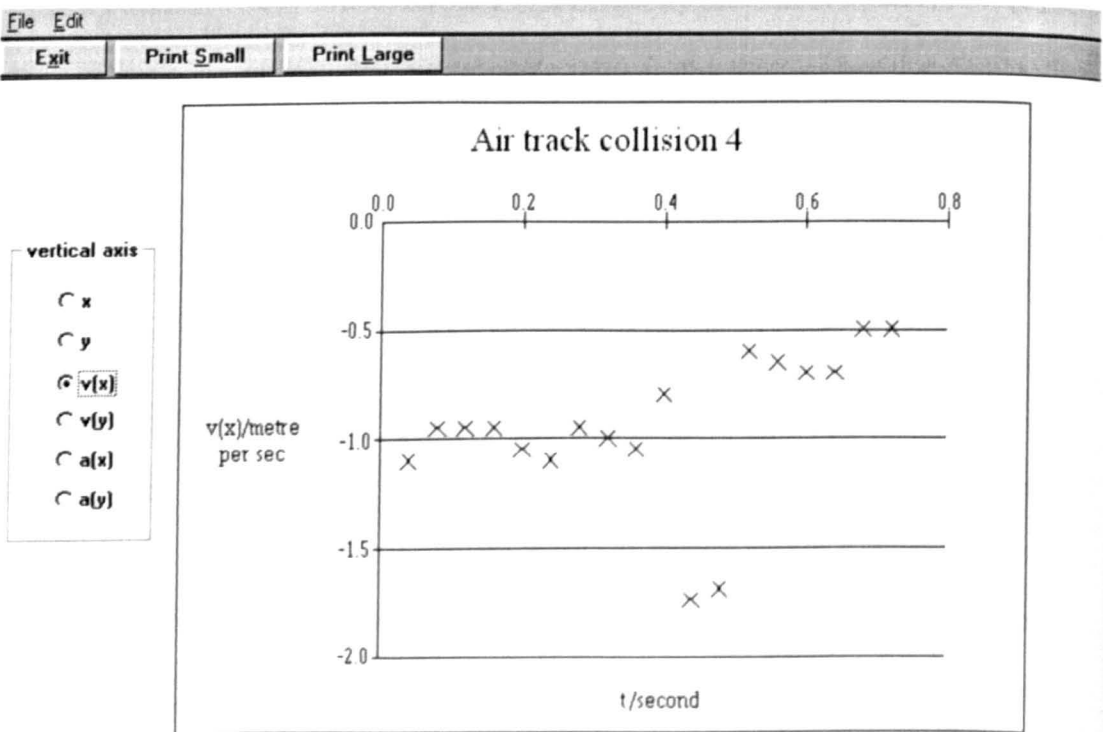


Fig. 6.5. Multimedia Motion: velocity graph.

CirclesColliding (CC)

The Interactive Physics simulations that were designed and implemented as part of this research are simulations of collisions where objects move on the screen and undergo elastic collisions with other objects (Fig 6.6). In Interactive Physics, simulations can be created by drawing objects on the screen. Physical quantities such as velocity, acceleration, momentum, angular momentum, kinetic energy, and friction force can be set to be measured while the simulation is performed. The simulations that were created for the purposes of this research were named CirclesColliding and will be from now on referred as CC. They are based on a combination of animation and Newtonian treatment of the underlying physics model.

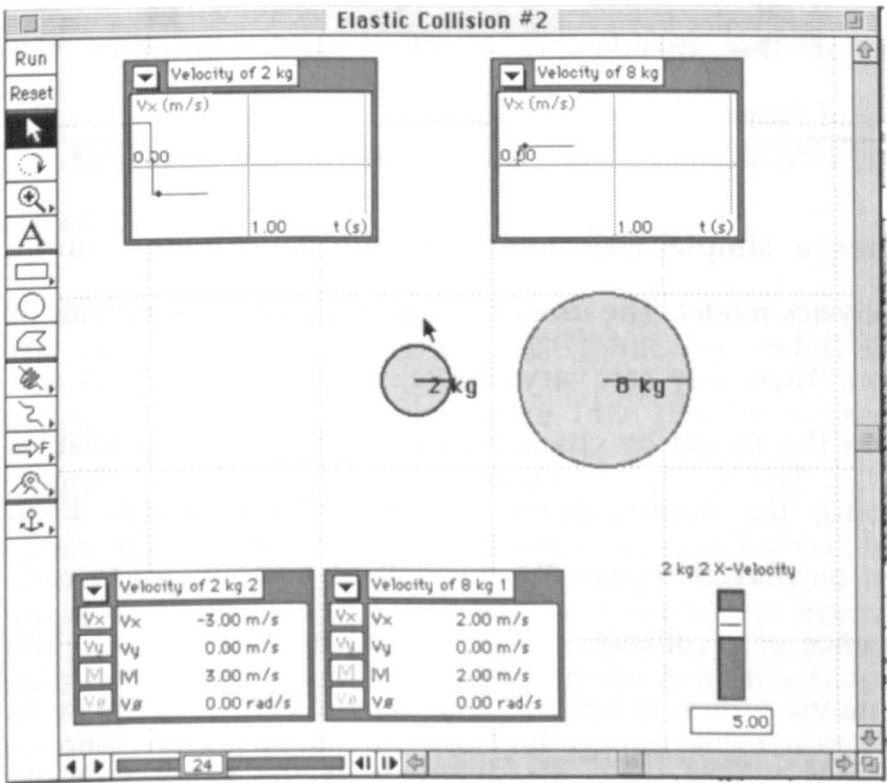


Fig. 6.6. CirclesColliding1 (CC1).

In the first simulation (referred from now on as CC1, Fig. 6.6), masses collide linearly on the computer screen and the program keeps track of the velocities and the elapsed time. It has a schematic interface in terms of the masses' representation; the colliding bodies are just circles (representing spherical objects with an indication of the velocity of each one with the use of vectors) moving in a non-gravitational space. The interface in CC constitutes a proper hybrid screen with digital and graphical displays of the values of velocities before and after the collision. These values can be displayed as numbers, graphs, or animated vector displays attached to the centre of mass of each object. Thus this version represents an environment with low fidelity (idealised animated objects) which is rich in providing complementary information to the users. The underlying model is equally simple (linear collisions, where only the x components of the speeds are needed) and simulates the fundamentals of Newtonian mechanics.

CC1 combines a simple user interface with an equally simple underlying physics model. The users can watch Quick Time movies of the simulation. Then they can vary the velocities of the masses and watch, explore the model by changing the conditions and variables and visualising the consequences of such manipulation. Each sequence can be played repeatedly through as a movie. Also each moving sequence of a collision can be played frame by frame. The Quick Time movie option is helpful, and the window is adequate in size (unlike MM whose main disadvantage is the small window display). The users can also watch in parallel with the objects' motion a digital display or graphs of the velocities of the participating objects.

Another version of the same type of simulation (low fidelity collisions of spherical objects), CC2, was also used (Fig. 6.7). It is a two dimensional collision, thus increasing the value of the complexity of the simulation from low to medium.

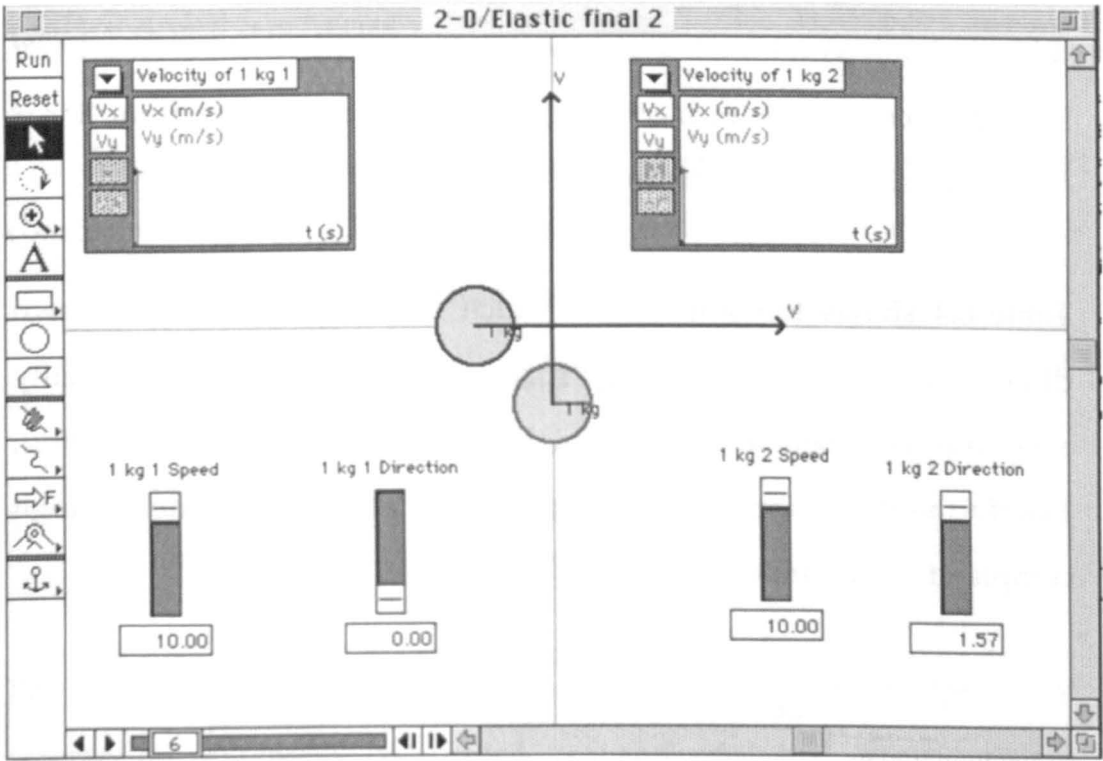


Fig. 6.7. CirclesColliding2 (CC2).

The interface is the same as in CC1 but the underlying model is different: while it has the same low fidelity representation of animated circles (representing masses) moving and colliding on the screen, the complexity level is different because the vectorial nature of linear momentum and speed has been taken into account. The two animated circles (masses) can move in the two dimensional space (the number of variables for controlling the simulation is increased because both x and y velocities are needed for determining motion). To this end there are gliders which determine the direction of motion

of the masses. There are again graphical representations of the results, digital displays of the values of the velocities before and after the collision and an indication of the velocity of each one with the use of vectors.

CirclesColliding presented characteristics which made it suitable for this study: it combined a simple interface with the possibility of having discrete cases of increasing complexity by moving from linear one-dimensional collisions to two dimensional ones.

Table 6.4 shows the simulations which were used, placed in a two dimensional fidelity-complexity space. Two extremes on the fidelity axis were represented by MM (high fidelity) and CC1 (low fidelity). Finally the third simulation CC2 corresponded to a low fidelity, high complexity combination.

| | Low fidelity | High fidelity |
|-----------------|----------------------------|---------------------------|
| Low complexity | CirclesColliding1 (CC1) | Multimedia Motion (MM) |
| High complexity | CirclesColliding2 (CC2) | |

Table 6.4. Simulations on the fidelity-complexity space.

An outline of the studies is presented in Table 6.5. Two groups of 12 students interacted with MM and CC1 respectively. The third simulation, CC2 was only used in a pilot trial with two users in order to explore users' perceptions of a high complexity, low fidelity environment.

| Subjects | Simulation | Fidelity | Complexity |
|-----------------|------------|----------|------------|
| Group 1 N=12 | MM | High | Low |
| Group 2 N=12 | CC1 | Low | Low |
| Group 3 N=2 | CC2 | Low | High |

Table 6.5. Outline of the studies.

The approach taken was a detailed analysis of a variety of complementary data. The students (see also 7.2.1 and 8.2.1):

- (i) answered a questionnaire and pre test
- (ii) interacted with the simulations by completing a number of tasks from a work-sheet,
- (iii) answered a post test and
- (iv) took part in post-interaction interviews.

For each pair, there was an hour’s annotated transcription of interaction, extensive completed pre and post test questionnaires (corresponding to 20 minutes of completion time), which covered conceptual change and attitudes to the simulation attributes and transcribed interviews (10 minutes of completion time). Consequently, the use of small size groups of participants under scrutiny was decided. Research which combines quantitative and qualitative analysis of this variety of data is difficult to run using big sample statistics. This resulted in having one group of 12 for each study. Certainly a potential drawback of using small samples is that it makes more difficult establishing statistical significance.

The CC2 simulation was not further used. The two users (experts) who interacted with it had difficulty in carrying out the worksheet tasks, because of the increased complexity of the simulation. The complexity level made it unsuitable for novices, as were the students of these studies.

6.3.3. Design of questionnaires

The main interaction with the simulation consisted of a number of tasks. A predict-observe-explain approach (Gunstone, 1988) to the structure of the task was chosen, because it provides an approach to securing measurable outcomes of the students' interaction with the simulation (see 3.4)

The students who participated in the studies (Table 6.5) completed pre and post test questionnaires (Appendix 1, p13, p18). The pre test questionnaires consisted of :

- questions on the subjects' experience on computers, science and simulations.
- questions on their understanding of the physics context of the simulated experiment (momentum conservation law). Most of these questions were taken or adapted from the APU Science in schools: Age 15 report (Welford et al, 1983).
- questions asking them to predict the outcome of linear collisions (subsequent motion of two masses) with a variety of masses and initial conditions.

Post-test questionnaires

The students repeated the predictions they had made in the pre test, as part of the post-test questionnaire. The aim was to detect changes as a result of the interaction with the simulation. The next part of the investigation examined how students reacted to the design of the interface by measuring their reaction to the features of the simulation, and also their attitudes. To this end the students were also asked:

- their opinion about their performance, after the interaction with the simulation.
- their opinion about the simulation (interface and whether the simulation helped them to understand better the simulated phenomenon).

6.3.4. Interaction with the simulation

Data were collected by observing the students interacting with the simulations. Their interaction was video-taped and their protocols transcribed.

In the studies the users worked independently of the teacher, in pairs, using a worksheet for guidance. The students worked in pairs because this technique has proved very useful in stimulating think aloud protocols, as individual subjects often forget to think aloud, or find it difficult to make their thoughts explicit if they are working alone (O' Malley et al, 1985; Draper, 1992). Secondly subjects are more likely to speak about problems they are having if they know that others are experiencing them too.

Another reason for having pairs was that the students would have the opportunity to explain things to each other, without the intervention of a teacher or the researcher. The pairing was decided after observing the participants of the pilot study, where in Multimedia Motion pairing minimised intervention from the researcher who was in the same room, collecting the data and keeping the observation protocols. No guidance was given and he only intervened where and when technical support was needed. This minimised the observer's influence on the students' thinking by avoiding a potential one to one dialogue with the students, which had tended to happen in the other pilot study (Gravitas, Chapter Three). However, it should be pointed out that in tasks which are completed in pairs some learning may be due to working with a more able or informed partner.

Laurillard (1992) also argues that putting students to work in pairs on a simulation increases the chances that they will carry out the task on which they are engaged in. She argues that this is a result of the students retaining a more generalisable, articulated account of what was happening in the system than if they react to it in a way that more closely resembles their interaction with the real world. Other researchers have explored methodological approaches to study collaborative learning with simulations, see e.g. Whitelock & Scanlon (1996), Issroff (1992). In this research learning is taken to be the individual's cognitive gain. However, as students worked in pairs their cognitive development cannot solely be attributed to working with the computer.

6.3.5. Nature of the tasks

The main interaction with the simulation consisted of a number of tasks. Tasks for both simulations were intended to be as similar as possible. A predict-observe-explain approach (Gunstone, 1988, Chapter Three) was chosen because:

- it provides an approach towards measurable outcomes of the students' interaction and performance with the simulation. This technique was tested successfully with the participants of the ColaCollision study.
- Setting tasks to the students (to investigate if physics laws apply) helps to ensure that they will not interact aimlessly with the simulation. The pilot study showed that it is difficult to keep the learner's attention and encourage persistence with the problem without clearly set tasks.

The only disadvantage of having a set of tasks was the time constraint. Following a predict-observe-explain task is time consuming, especially when combined with detailed questionnaires and interviews.

6.3.6. Interviews

The one to one interviews with the students concerned the outcomes of their interaction (performance, comparisons of simulations, etc.). The users were encouraged to describe the simulation that they used, their opinion of the simulation (difficulty, interface), their opinion of their performance, and in particular how performance relates to the degree of realism they were offered.

The interviews also aimed to pick up on any areas noted from observations while they were working with the program. The aim was to explore the relationship between the characteristics of the simulation and the evidence of their understanding of the relevant physics concepts.

However it should be pointed out that, useful as they were in eliciting cognitive and affective comments from the interviewees, a possible disadvantage of the interview data compared to the observation data was the possibility of the students wanting to please the researcher while they were answering questions and expressing opinions.

6.4. Data analysis

The outcomes of the experiment (interviews and questionnaires, videotapes of the students' interaction with the simulation) were examined in relation to:

- a. the students' performance. First the learning outcomes of their performance were investigated to show how effective each simulation could be considered in terms of use for instructional purposes. The transcripts of their interaction were closely examined to detect how each simulation encourages effective scientific reasoning.
- b. the interface and how it was referred to by the students in their interaction, conversations, responses to questionnaires and interviews. Also how its design influenced the interaction.

- c. the students' opinion of their performance and the simulation, and also likes and dislikes which might affect motivation.

The students' comments from the transcripts of interaction, worksheets, pre and post test questionnaires and interviews were classified as cognitive and affective (Table 6.6). The cognitive comments relate to the educational experience of interacting with the simulation and the learning outcomes. The affective ones are related to the students' attitudes and feelings to the software in terms of ease of usability and preferences. Jacques (1995) points out that until recently approaches to usability evaluation focused little on determining users' subjective satisfaction and more on ease of use and system learnability, but interest in users' perception is growing. Another aspect of the collected data is examined in this thesis, drawing from completed questionnaires and semi structured interviews, where the users described their experience with the simulations. An analysis of the affective comments of the users is carried out. These are related to the students' attitudes and feelings towards the software in terms of ease of usability and preferences. The data were examined and the outcomes were combined to determine how comparable systems were used by the students. The idea was that the learning outcomes in the physics domain and the users' attitudes to the simulation would provide insights on the design and use of simulations.

OUTCOMES OF THE STUDIES

| Cognitive | Affective |
|----------------------------------|--|
| Student performance | Users' comments Opinions about performance and simulation |
| Sources | Sources |
| Transcripts of interaction | Transcripts of interaction |
| Interaction worksheets | Worksheets |
| Pre and post test questionnaires | Post test questionnaires |
| | Interviews |

Table 6.6. Classification of outcomes.

6.4.1. Learning and usability

One common distinction made in the study of usability of educational software is between requirements for the interface designed to support performance and the requirements of interfaces designed to support learning (Rappin *et al*, 1997; Mayes and Fowler, 1997). Furthermore Squires and Preece (1997) claim that thinking of learning and usability as independent issues leads to superficial evaluations of educational software. Usability applies loosely to educational software, as ease of use has a different meaning in an educational setting.

Mayes and Fowler (1997) argue that the usability of educational software cannot be measured in the same terms as other kinds of work, since learning is a by-product of understanding rather than an activity which can be supported directly. Their claim is that usability, if used without caution, can support not constructivist but instructivist views of learning, when ideally it should support not only the “impact of content presentation on the learner”, but also “the

learner in the performance of tasks which have been designed to engage her in active problem solving” (ibid.). Thus, they argue for a view of usability which emphasises learning outcomes.

As Nielsen (1993) points out, from a usability perspective questionnaires and interviews are indirect methods, since they do not study the user interface itself but only users’ opinions about it. Nielsen’s (ibid.) view is that one cannot always take user statements at face value and that data about people’s behaviour should give precedence over people’s claims of what they think they do. However educational software, especially in a domain like physics, should keep the balance between people’s perceptions and conceptual learning issues.

The written and verbal comments the students made were examined from the point of view of usability. A useful variable for examining the students’ responses was user perception of performance (Table 6.7).

USABILITY MEASURES

User Satisfaction

| | |
|--|---|
| Perception of performance: Satisfaction | Perception of software effectiveness: Efficiency |
|--|---|

Table 6.7. Usability measures.

The students’ satisfaction in terms of usability of the simulations (user satisfaction) was analysed by also examining the user perception of software effectiveness (efficiency). Efficiency (Nielsen, 1993) refers to the user’s feeling that the software is enabling the task(s) to be

performed in a quick, effective and economical manner or is hindering performance.

The analysis of the interviews and questionnaires also produced a number of factors which either were considered fundamental or were mentioned frequently by the users in their affective comments. The main factors that guided the analysis of the interviews and free format answers in the questionnaires was the frequency and fundamentality of the issues raised by the users (Adams et al, 1997). This analysis produced a number of factors which can be influential on simulation design. The emphasis was less on formal methods of usability and more on general human computer interaction issues.

6.5. Conclusion

This chapter provided an outline of the design of the studies and the methodology used. A set of hypotheses was discussed which describes the implications of varying fidelity and complexity on students' learning of the domain of a simulation.

The first simulation on which the methodology described in this chapter is applied is Multimedia Motion (MM). The next chapter describes observations made with learners using MM. The findings are given and a connection is made to the main threads of this research.

Chapter Seven

The Multimedia Motion study: working with a high fidelity, low complexity simulation

7.1. Introduction

The chapter describes observations made with learners using Multimedia Motion (MM), an example of a high fidelity, low complexity simulation. An analysis of the procedure is followed by a detailed description of each study (participants, aims, annotated interactions). The emphasis is on the analysis of the questionnaires and video taped data of the actual interaction. In the end, the findings are given and a connection is made to the research hypothesis.

7.2. The Study

7.2.1. Subjects and procedure

Twelve A level students, median age 17, worked in their own school settings in Milton Keynes, London and Ipswich. The study ran in parallel to the lessons in the school in the students' free time and the participation was voluntary. In this aspect the experiments were an extra-curricular activity where the subjects volunteered to participate. Running a voluntary study was the only option because of the heavy workload of A level students. Both the researcher and the teachers in the schools which participated in the study felt that no extra pressure

should be exerted on the students. The teachers agreed to discuss in the classroom how the students could only gain from an activity which would complement their knowledge in the domain of the MM. Consequently, the main factor in determining the composition of the pairs was whether subjects were available and willing to participate in the experiment at the time. They formed both single and mixed gender dyads, as Table 7.1 shows:

| |
|---|
| Single sex dyads: 4 ; Female: 1, Male: 3 |
| Mixed dyads: 2 |

Table 7.1. Gender distribution in student's' pairs.

The A Level students were considered to be novices as they had only recently learned in school the content area of exploration in the simulations (Newtonian mechanics and conservation principles) and were encouraged to apply the knowledge gained in the classroom to new situations (see also 2.2).

Data were collected by observing the students interacting with Multimedia Motion (MM). The outcomes of the experiment (questionnaires and videotapes of the students' interaction with the MM) were examined in relation to conceptual shifts between pre test and post test, problem solving strategies, and their performance.

The students worked for two hours:

- (i) reasoning without the computer by answering a questionnaire and pre test, predicting motion after collisions. They were asked to predict the outcome of three collisions (20 mins),
- (ii) interacting with MM. There was no upper time limit but it was thought that about an hour was sufficient time for

completing the questionnaires and the tasks. The students completed a number of tasks collecting data and examining spreadsheets and graphs in order to carry out tasks from a worksheet,

(iii) repeating the pre-interaction questionnaire (10-15 mins) and
(iv) taking part in post-interaction interviews. In the one to one interviews they were encouraged to describe the learning environment that they used and in particular "how that description relates to the degree of realism they were offered" (Hennessy & O'Shea, 1993). Also the interviews aimed to pick up on any areas noted as being interesting while students were working with the program (10-15 mins).

The initial questionnaire asked students first about their experience with computers, the science courses they had attended in school and if they were also doing mathematics, since any mathematical knowledge would be helpful in dealing with the calculations in the tasks. Another part of the questionnaire investigated their previous knowledge on the nature of a computer simulation. This initial information was later combined with information received from their teacher who was asked to rate the students' ability. The students were also asked about the meaning of conservation laws and if they could come up with any relevant examples of a conservation law. The rest of the questionnaire asked the students to make predictions about the behaviour of masses after collision in three cases. These prediction questions are described in detail further on (see 7.3.1).

Video recordings of students were made while they were interacting with MM. These focused on the computer screen. At the same time,

the students' interaction while carrying out the set tasks, was audio taped. The subjects were both seated in front of the computer, which was controlled both by keyboard and mouse. In this way, each videotape consisted of a source of data, combining visual information on what the students saw on the computer screen with synchronous sound of the students' discussion in front of the computer. The quality of the audio tape recording and soundtrack on video was, in some cases, poor and difficult to follow, due to external noises (e.g. one of the schools was near a busy international airport). The video recordings and the observation schedules also gave the relative time spent on each section of the interaction.

7.2.2. The MM sequences

All the Multimedia Motion sequences that were used are videos of air track collisions, i.e. gliders moving on tracks and undergoing collisions with other gliders. Specifically, there is:

- an elastic collision where a moving object collides with a stationary one of the same mass (Collision 1, Fig. 7.1),
- a moving light glider which undergoes an elastic collision with a heavier stationary one and (Collision 4, Fig. 7.2) and
- a moving object which has an elastic collision with a moving object of the same mass (Collision 5, Fig. 7.3). In all the above cases the motion of the two objects is in the same straight line (linear collisions).

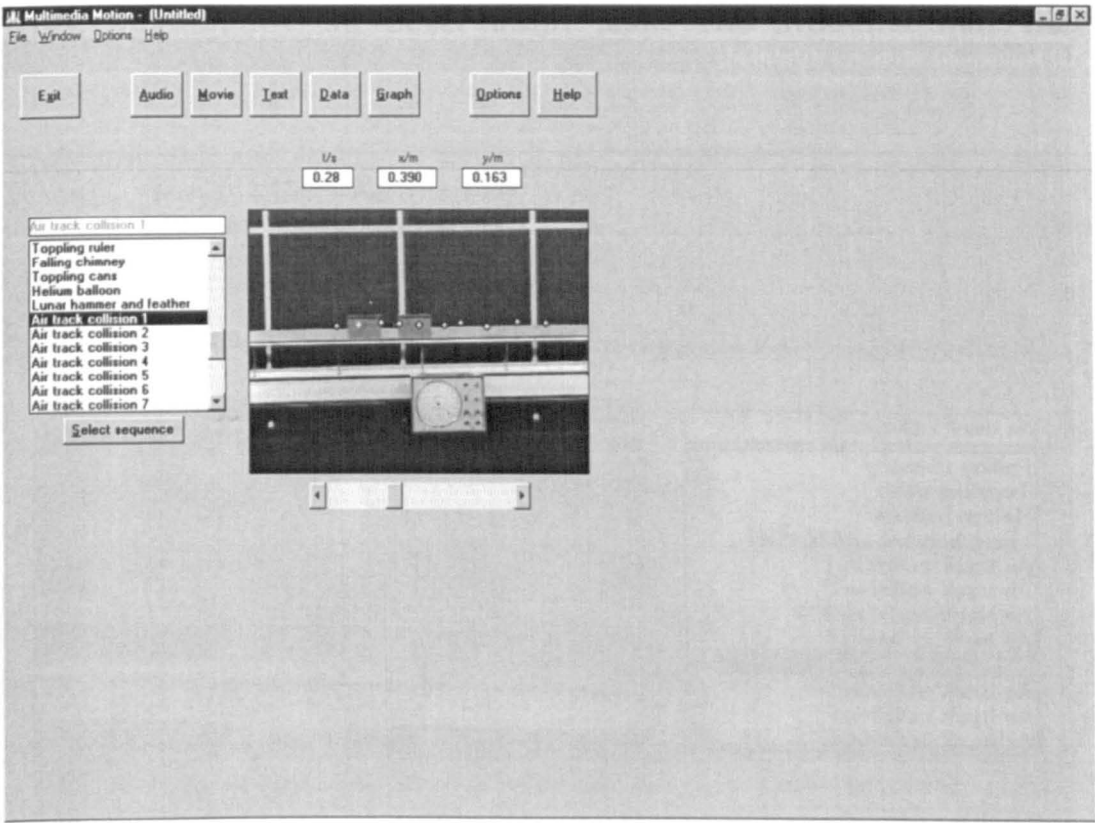


Fig 7.1.Multimedia Motion (Collision1).

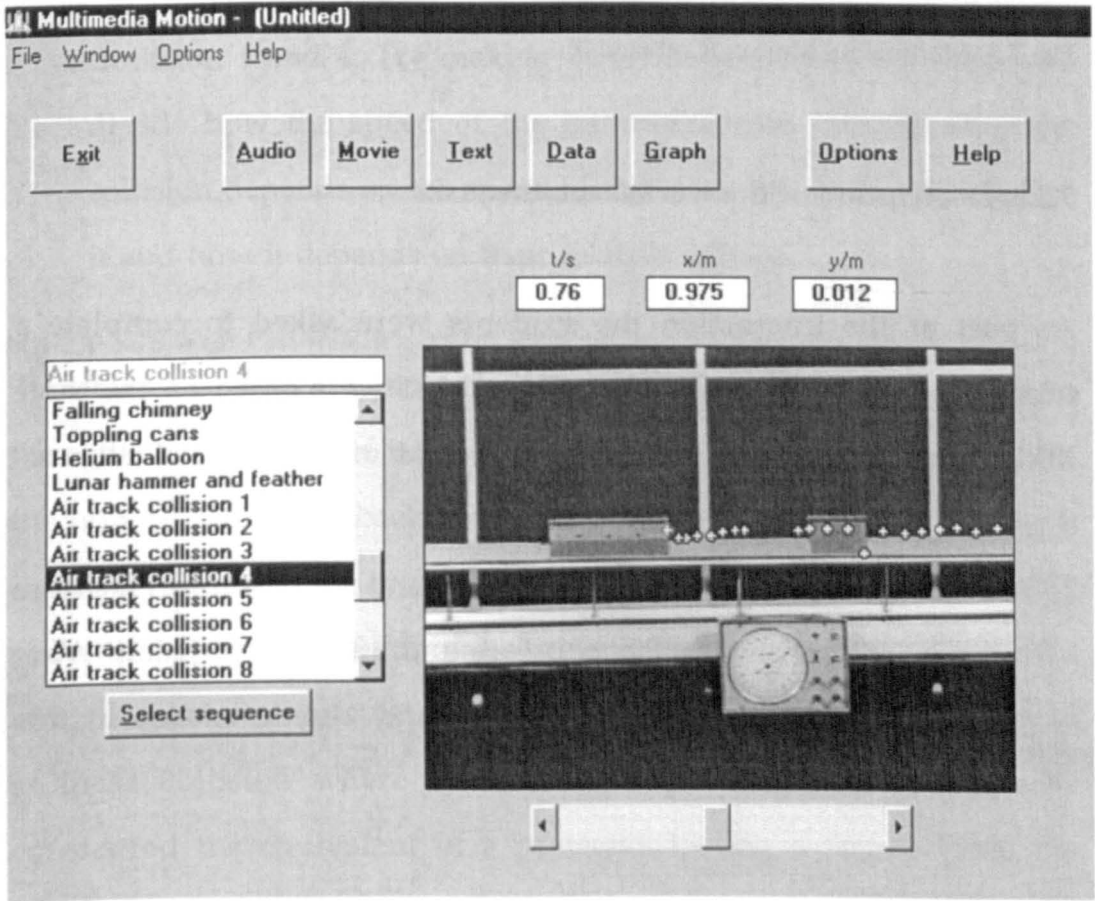


Fig 7.2. Multimedia Motion (Collision 4).

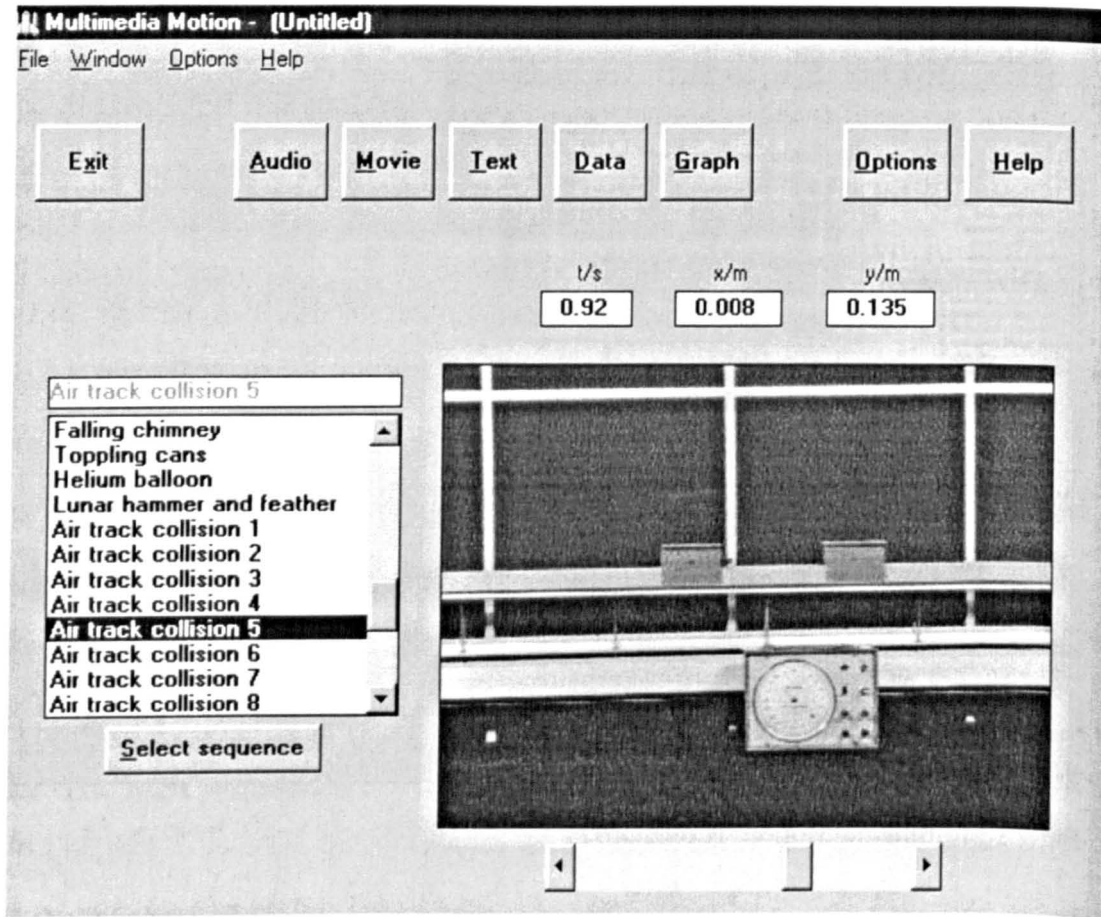


Fig. 7.3. Multimedia Motion (Collision 5).

7.2.3. Description of the worksheet: the tasks

As part of the interaction the students were asked to complete a number of tasks in a worksheet. These tasks were based on the three MM sequences. The tasks were posed in order of difficulty, as follows:

Collision 1 or 5: Explore the sequence and see if you can measure the velocities of the objects before and after the collision. What might happen to both momentum and kinetic energy in this kind of collision?

This was mainly an observation task. The students had the opportunity, after observing the sequence, to vary the velocities of the colliding masses, choose a setting and investigate the conservation laws of kinetic energy and momentum.

Collision 4: Use the sequence to measure how the momentum and kinetic energy of the two gliders change in the collision.

This was similar to the previous task, where the students were supposed to investigate how the collision affects the kinetic energy and momentum of the participating masses. This investigation was intended to help the students to get an idea of the new post-collision distribution of momentum and kinetic energy between the masses. It was also a first step towards the third and more difficult task:

Collision 1 and 4: Try making measurements that will help you decide how the speed of the immobile mass (target) after the collision depends on the speed of the other one (projectile) before it and how it depends on their relative masses.

The third task was the most challenging and it was chosen as it was thought that because of its greater difficulty would give the students the opportunity to go back to the sequences repeatedly and use them creatively in order to come up with a solution. It would probably provide opportunities for a lengthier negotiation and a repeated swapping between calculations and watching the sequence. The case of a linear collision where one of the masses is immobile can be considered the equivalent of a projectile hitting a target. From the point of view of physics, as Grimellini-Tommasini et al (1993) point

out, an important feature of head-on collisions between a projectile and a target at rest is that the projectile motion after collision is linked to the ratio between the masses of the two bodies; the projectile would continue its motion forward, stop or return on its way according to the ratio between its mass and the mass of the target (bigger than one in the first case, equal to one in the second case and smaller than one in the third case, as can be seen by solving the system of equations corresponding to the energy and linear momentum conservation laws, Appendix 1, p15 and Appendix 6).

In a collision of this type, the mathematical difference of the velocities of the projectile and the target after the collision is equal to the velocity of the projectile before the collision. If m_1 =projectile mass and m_2 =target mass, v = projectile velocity, v_1 = projectile velocity after the collision and v_2 = target velocity after the collision, the relationships between the velocities of the participant masses can be expressed as: $v=v_2-v_1$ and $v_1/v_2=(1-R)/2$, where R is the ratio of the two masses m_2/m_1 , by taking into account the laws of conservation.

It was hoped that the students would realise that the masses of the collisions and their ratio played a role in determining the velocities. Ideally they should come up with a relation between the three velocities (v , v_1 and v_2), and if not derive the actual relationship which governs the behaviour of the masses, probably reach some reasonable conclusion. To this aim they could use the sequences and vary mass and velocities, observe and keep track of their findings.

Table 7.2 shows the timing of the interaction with MM.

| | |
|---------------|-----------|
| Robert-Daniel | 39 mins |
| Barry-Judith | 42 mins |
| Nora-Irene | 38 mins |
| Duncan-Jeremy | 50 mins |
| Roger-Ray | 45 mins |
| Agnes-Simon | 47 mins |
| Average | 43.5 mins |

Table 7. 2. Time taken by each pair working with the simulation.

7.3. Data analysis

7.3.1. Questionnaire analysis

Previous experience with computers

Before each session the students completed a questionnaire. The first question was about their experience in computers, which was mainly in using the school computers (word processing and spreadsheets). Some of them had also explored multimedia environments, and had used data logging software.

The range of the students' previous experience with computers is given in the table below (Table 7.3).

| | |
|---|----------|
| Using school computers: word processing, spreadsheets | 9 or 75% |
| Using school computers: data logging, multimedia | 4 or 33% |
| Other (e.g. games, etc.) | 2 or 17% |
| No previous experience | 2 or 17% |

Table 7.3. MM: Previous experience with computers.

Science courses in school

All students had chosen A level physics in school and a number of them had also chosen A level Chemistry and Biology (as can be seen from Table 7.4).

| | |
|----------------------------------|------------|
| GCSE modular science | 12 or 100% |
| A level physics | 12 or 100% |
| A level Chemistry and/or Biology | 6 or 50% |

Table 7.4. MM: Science courses in school.

Mathematics courses in school

Additional information was obtained from the school regarding the courses in Mathematics the students had done (GCSE) or were doing (A level Maths), Table 7.5.

| | |
|---------------|------------|
| GCSE Maths | 12 or 100% |
| A level Maths | 4 or 33% |

Table 7.5. MM: Mathematics courses in school.

Previous knowledge of simulations

The range of the students' previous experience with computer simulations is given in the table below (Table 7.6).

| | |
|--|----------|
| I have used a computer simulation before | 4 or 33% |
| I have never used a computer simulation | 6 or 50% |
| I don't know | 2 or 17% |

Table 7.6. MM: Previous knowledge of simulations

Some students provided sensible definitions of what a computer simulation is, as can be shown by the following excerpts from their answers:

"A computer simulation is a programme designed to make the mind think that you are in the real life situation which the computer is portraying." (MM, Q1, S10, p4).

or,

"A computer simulation is either a programme that can record accurate information from an experiment or actually simulate the experiment itself after someone inputting conditions." (MM, Q1, S12,p4).

and,

"A computer simulation is a program designed to simulate a part of life, e.g. moving, finance, etc. Many games are simulations e.g. sports simulations, flight simulations, Sim city (the simulation of building a city). Computer simulations are usually as close to reality as possible, so that you can ask: "what if?" to many situations, and the simulation to show you what should happen." (MM, Q1, S9, p4).

Pre and post test comparison outcomes

In the second part of the pre test questionnaire the students' initial knowledge on collisions was tested. They were first asked to answer a question on the meaning of conservation laws:

- What is meant by a conservation law? Can you give any further examples of conservation laws?

The subjects were then pretested with a questionnaire which was based on Whitelock *et al* (1993a), Appendix 1, p14. Data were obtained by asking the students to anticipate the behaviour of masses in collisions that differ one from the other in the values of the masses and their velocities. The students were asked to predict the subsequent motion of two masses after collision for the following 3 conditions:

Condition 1: If you have two equal masses moving at the same speed and colliding (Fig. 7.4) what will happen after the collision?



Fig. 7.4. Condition 1.

Condition 2: If a small mass collides with a much bigger immobile mass (Fig. 7.5) what will happen after the collision?



Fig. 7.5. Condition 2.

Condition 3: If a big mass collides with a small immobile mass (Fig. 7.6) what will happen after the collision?

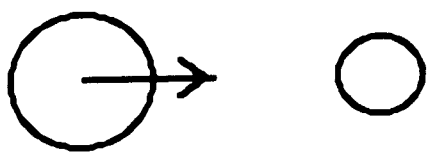


Fig. 7.6. Condition 3.

In the post test all three questions were repeated. Table 7.7 shows pre and post test predictions of all the participating students.

| Students | Prediction 1 | | Prediction 2 | | Prediction 3 | |
|-------------|--------------|---------|--------------|---------|--------------|---------|
| | Pre | Post | Pre | Post | Pre | Post |
| Daniel, S1. | Correct | Correct | Wrong | Correct | Wrong | Correct |
| Robert, S2 | Wrong | Correct | Correct | Correct | Wrong | Wrong |
| Barry, S3 | Correct | Correct | Correct | Correct | Wrong | Correct |
| Judith, S4 | Wrong | Correct | Wrong | Correct | Wrong | Correct |
| Nora,S5 | Wrong | Correct | Wrong | Correct | Correct | Correct |
| Irene, S6 | Wrong | Wrong | Correct | Correct | Wrong | Correct |
| Duncan, S7 | Correct | Correct | Correct | Correct | Correct | Correct |
| Jeremy, S8 | Correct | Correct | Wrong | Correct | Wrong | Correct |
| Roger, S9 | Correct | Correct | Correct | Correct | Correct | Correct |
| Ray, S10 | Wrong | Wrong | Wrong | Wrong | Wrong | Correct |
| Agnes, S11 | Correct | Correct | Correct | Correct | Wrong | Correct |
| Simon, S12 | Correct | Correct | Correct | Correct | Wrong | Correct |

Table 7.7. MM-pre to post test shift.

The percentages of correct pre test and post test correct answers are shown in Table 7.8. The comparison between the pre and post interaction tests showed that there was a shift in the number of correct predictions:

| MM | Prediction 1 | Prediction 2 | Prediction 3 |
|-----------|--------------|--------------|--------------|
| Pre test | 58% | 58% | 25% |
| Post test | 83% | 92% | 92% |

Table 7.8. MM, Preliminary and post test: Percentage of correct answers.

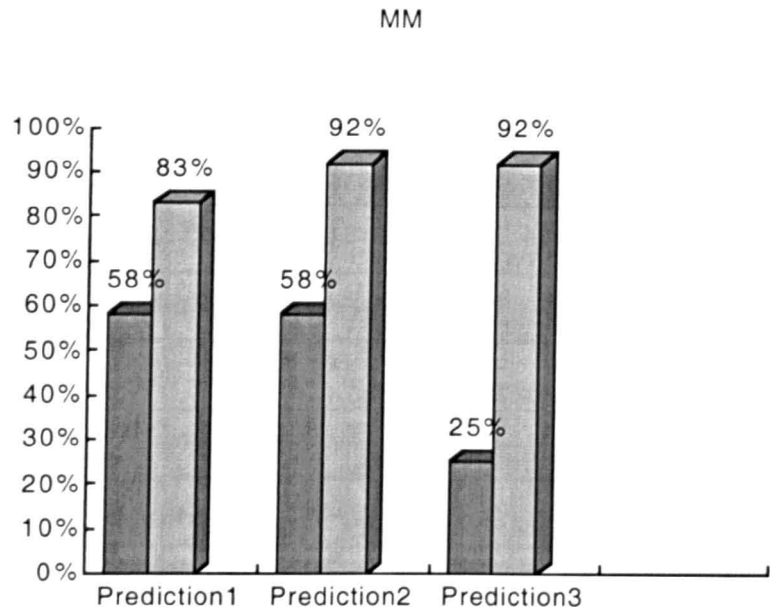


Fig. 7.7. Pre to post test percentages of correct answers.

A one-tailed Wilcoxon signed-ranked test was carried out to see if there was a significant difference between the pre and post test means of the total predictions scores. The result of the Wilcoxon test (Table 7.9) showed that there was a significant difference between the pre and post test total prediction scores ($T=0$; $n=10$; $p<0.05$).

A statistical analysis using McNemar’s test (binomial) was also carried out (Table 7.10 and Fig 7.7). The 12 subjects (MM users) took part in the cross-over trial and the two levels of the variable (the students’ prediction) corresponded to the values “correct” and “wrong”. The test statistic was compared with a binomial distribution to determine the probabilities of the possible outcomes and to investigate its significance.

| Student | Pre Test | Post Test | Sign of difference | Size of difference | Rank of difference |
|---------|----------|-----------|--------------------|--------------------|--------------------|
| S 1 | 1 | 3 | - | 2 | 8 |
| S 2 | 1 | 2 | - | 1 | 3.5 |
| S 3 | 2 | 3 | - | 1 | 3.5 |
| S 4 | 0 | 3 | - | 3 | 10 |
| S 5 | 1 | 3 | - | 2 | 8 |
| S 6 | 1 | 2 | - | 1 | 3.5 |
| S 7 | 3 | 3 | | 0 | |
| S 8 | 1 | 3 | - | 2 | 8 |
| S 9 | 3 | 3 | | 0 | |
| S 10 | 0 | 1 | - | 1 | 3.5 |
| S 11 | 2 | 3 | - | 1 | 3.5 |
| S 12 | 2 | 3 | - | 1 | 3.5 |

$\sum_{R=-} = 55$ $\sum_{R+=} = 0$

Table 7.9. Wilcoxon test for MM.

McNemar’s test indicated that there was a shift in the students’ conceptual learning, but there was one statistically significant improvement, in the third prediction ($p<0.05$): case of a big mass colliding with an immobile smaller one, where there was a big cross-over (8) of “wrong” to “correct” predictions. The layout of the test (see also 8.3.1) helped to identify interesting cases for qualitative analysis of the students’ interactions. This analysis of the interaction of a number of pairs was undertaken to find common characteristics and strands and to highlight the general style of interaction.

MM

| | | Post test | | |
|----------|-------------|-----------|-------|-------|
| Pre test | Prediction1 | Correct | Wrong | Total |
| | Correct | 7 | 0 | 7 |
| | Wrong | 3 | 2 | 5 |
| | Total | 10 | 2 | 12 |

McNemar’s test, df=1 (binomial), p=0.2500.

| | | Post test | | |
|----------|-------------|-----------|-------|-------|
| Pre test | Prediction2 | Correct | Wrong | Total |
| | Correct | 7 | 0 | 7 |
| | Wrong | 4 | 1 | 5 |
| | Total | 11 | 1 | 12 |

McNemar’s test, df=1 (binomial), p=0.1250.

| | | Post test | | |
|----------|-------------|-----------|-------|-------|
| Pre test | Prediction3 | Correct | Wrong | Total |
| | Correct | 3 | 0 | 3 |
| | Wrong | 8 | 1 | 9 |
| | Total | 11 | 1 | 12 |

McNemar’s test, df=1 (binomial), p=0.0078.

Table 7.10. MM: McNemar’s test.

7.3.2. Discussion of pairs, pre to post gain and interaction

This section discusses in the form of annotated transcriptions the interaction of three pairs, giving their age and ability ratings. The students’ pre to post test gain is also shown. Then an account of their interaction with MM is given. This description is based on the transcript of the interaction, while the pairs of students were carrying out the tasks from the worksheets. Three out of the six pairs were chosen selectively to cover representative styles of strategies and interactions. The criteria for selecting these three pairs for analysis were pre to post test shift, interactions in which the participants

articulated clearly their think aloud protocols and the inclusion of different interaction styles which revealed possible implications for the learning environment's complexity and fidelity. One pair of students was chosen who did not fare well in terms of achieving pre to post prediction gain and another two who did well. In the transcripts an effort was made to include all significant remarks, comments and bits of dialogue.

S1,S2: Daniel and Robert

The first pair of students, Robert and Daniel, are 16 years old. Robert was rated as of low ability by the teacher while Daniel was rated as of high ability.

Daniel in his pre and post test answers gave two different but equally acceptable explanations of conservation laws. In the pre test, he stated that in a conservation law *"a quantity is conserved, i.e. the quantity at the start and the end of a process is the same"* (MM, Q1, S1, p4), mentioning as examples energy and momentum. In the post test he gave a less precise definition of a conservation law (*"a statement to say how and where something is saved or conserved and by what means"*) (MM, Q1, S1, p4), but the example he used was more detailed. He described how a conservation law applies to energy (*"energy cannot be created or destroyed, it can only be transferred from one form to another"* (MM, Q1, S1, p4)).

| | Prediction 1 | | Prediction 2 | | Prediction 3 | |
|-------------|--------------|---------|--------------|---------|--------------|---------|
| | Pre | Post | Pre | Post | Pre | Post |
| Daniel, S1. | Correct | Correct | Wrong | Correct | Wrong | Correct |
| Robert, S2 | Wrong | Correct | Correct | Correct | Wrong | Wrong |

Table 7.11. Pair S1: Robert, S2: Russell, predictions.

Daniel got two out of three predictions wrong in the pre test (Table 7.11), but improved after the interaction (all predictions correct). His second pre test prediction was incomplete, referring only to the small mass, not mentioning what happens to the big mass after the collision. He rectified this in the post test by predicting that *“the small mass will return at a slower speed, while the big mass will move in the other direction”* (MM, Q1, S1, p7), which was adequate in the sense that it gave the transfer of momentum and the correct post collision directions of the two masses. His third pre test prediction was incorrect because he suggested that the large mass would rebound off the small mass, but again he gave a correct prediction in the post test by suggesting that the two masses *“will move in the same direction”* (MM, Q1, S1, p9).

Robert did not give a concise explanation of the meaning of a conservation law or any examples in the pre test questionnaire. His was a short answer stating that *“to conserve is to keep”* (MM, Q1, S2, p4) and he did not answer the same question in the post test.

He got one prediction correct in the pre test and two in the post test (Table 7.11). His second pre test and post test predictions were correct, suggesting in the pre test that *“the small mass will rebound, and the*

large (immobile) mass will move in the opposite direction" (MM, Q1, S2, p7) and just rephrasing that in the post test. Both his third pre and post test predictions were not adequate, though there was a slight improvement as he moved from predicting that the big mass "*can give all its kinetic energy to the small mass*" (MM, Q1, S2, p9), meaning that the big mass would stop after the collision, to suggesting that "*the big mass will give some of its kinetic energy to the small mass*" (MM, Q1, S2, p9) in the post test. In both cases he did not make any predictions on the direction the second mass would be moving.

During the interaction Daniel's motivation was higher and he took most initiatives in completing the tasks. The positive part of Robert's contribution was that although he was not as willing as Daniel, his questions and objections to the procedure instigated discussion on important issues of the collisions under study: the effect of forces and the conservation laws. They started by deciding to measure velocities before and after and negotiated where exactly they should click on the objects on the screen (Transcript 7.1).

S1. You want to point on that one so as to measure its velocity before and after.

S2. Try one corner?

S1. Which corner?

S2. Bottom corner.

S1. There.

S2. Just use this one first (mass on the left).

Daniel predicted that the mass after the collision would go off at exactly the same velocity since the two gliders in Collision 1 are equal. After calculating total kinetic energy before, they concluded that some energy was lost during the collision. Transcript 7.2 follows their disbelief and discussion about the discrepancy between prediction and outcome.

- S1. They are the same masses, so they have the same velocity.
- S2. No. Some of it might be moved over.
- S1. Kinetic energy isn't conserved.
- S2. Isn't it?
- S1. No.
- S2. Where is it lost? Since there was no friction.
- S1. Sound. No, not really.
- [They look again at the graphs].
- S2. It can't be lost. It can't.
- S1. It can. It's kinetic energy. It's an inelastic collision.
- S2. It cannot be lost in friction.
- S1. I don't know what it is lost in. There must be some tiny friction... It's lost somewhere. Inelastic or elastic one? Which one is it inelastic or elastic?
- S2. Elastic is when they come together and kick off in the opposite side and inelastic is when they stop together.
- S1. It's an elastic collision while the other one was perfectly inelastic... Energy is conserved anyway, it's just converted to something else.

| Time | Student activity | Comment |
|------|---|--|
| 0.00 | Collision 1. measure the velocity of the masses before and after the collision. Plot points on the left blue glider. | Choose a corner of the glider for clicking. |
| 0.02 | Examine graphs of v_x and v_y . | Daniel predicts that the velocity will be the same post collision. Robert is not sure. |
| 0.04 | Plot points on the right blue glider. | Discuss why the velocity of the second mass is slightly smaller than predicted. |
| 0.06 | Go to the text facility. | Robert attributes the difference to experimental error. |
| 0.07 | Collision 4. Plot points on the green glider. | Daniel more persistent. Robert's style is reactive to what Daniel does and says. |
| 0.10 | Plot points on the blue glider. | |
| 0.12 | Go to the text facility. | Discuss direction of the gliders post collision. |
| 0.14 | Calculate momenta and kinetic energy before and after. | |
| 0.16 | | Discuss why there is a loss of kinetic energy post collision. |
| 0.18 | | Discuss if there is friction or not. are not sure what an elastic or inelastic collision is. |
| 0.20 | | Agree that there is a slight loss of kinetic energy where "it is converted to something else" and "lost in elastic collision". |
| 0.21 | | Discuss their strategy for task 3. decide they need to look at the different air tracks. |
| 0.21 | Collision 4. Watch the sequence frame by frame. | Decide to get some "better data" in Collision 4. |
| 0.26 | Plot points on the green glider. | Discuss about the effect of forces on the colliding masses. |
| 0.29 | Examine graphs of v_x . | |
| 0.32 | | Attempt to extract a relationship of momenta. |
| 0.34 | Plot points on the green mass (air track 4). | |
| 0.39 | | Discuss the mechanics of the collision (what happens to momentum). |

Table 7.12: Observation schedule of S1: Robert and S2: Daniel.

Though it was not mentioned during their discussion, Robert had explained this “inconsistency” in his worksheet as “*loss of 0.1ms-1 experimental error*” (MM, W, S2, p12) and concluded that “*In a total(ly) elastic collision both momentum and kinetic energy will be passed on.*” (MM, W, S2, p13). In his worksheet Daniel did not attempt to explain their findings and also concluded that “*both kinetic energy and momentum are conserved*” (MM, W, S1, p13).

Robert used a consistent but faulty model to explain outcomes of collisions: the masses either stop (inelastic) or they do not (elastic) immediately after the collision (presumably because of friction and loss of energy). Daniel seemed to accept Robert’s model of the distinction of elastic and non elastic collisions, though he had correct views on aspects of the collision. They used the above criterion to classify collisions in the second sequence.

At the end of the second task, in his worksheet Daniel concluded that “*It is an elastic collision- momentum is conserved but approx. 1/10 J kinetic energy is lost.*” (MM, W, S2, p14) without attributing this loss to any specific reason, while Robert attributed it again to experimental error.

Daniel was aware of Newton’s laws while Robert was uncertain about the existence and the effect of forces on the colliding masses, as the following excerpt from their interaction shows (Transcript 7.3).

S2. What about the forces? It should accelerate... It stopped and started going again.

- S1. There is no constant force. We have uniform velocity. First law of motion.
- S2. The first few seconds. The force is acting on it.
- S1. It's come from wherever it started. So in the first few seconds... That's because the force was acting on it. The magnetism between them... There is no force on this one, so there must be uniform velocity.

Transcript 7.3.

(MM, T, S1-S2, p26)

The more open ended nature of the third task compared to the first two confused them and they did not conclude the session with some acceptable answer to task three. Daniel only made an attempt to relate the ratio of masses to the ratio of momenta. Robert concluded in the worksheet echoing Daniel's thinking aloud protocol that *"a slight change in velocity will cause a large change in v square which means a large change in kinetic energy"* (MM, W, S2, p17), while Daniel did not write down any conclusion.

Throughout their interaction Robert and Daniel extracted the values they needed from the graphs of velocity and they hardly looked at the data spreadsheets. Discrepancies in the collected data caused disbelief and perplexed them as to whether the collisions obeyed conservation laws. They used the MM sequences to verify their faulty models. Occasionally they would revert to stating the conservation laws correctly, however they did not attempt to use the laws to explain their models.

S3,S4: Barry and Judith

The second pair of students, Barry and Judith, were 17 years old. Barry was rated as of medium ability by the teacher, while Judith was rated as able and hard working.

| | Prediction 1 | | Prediction 2 | | Prediction 3 | |
|------------|--------------|---------|--------------|---------|--------------|---------|
| | Pre | Post | Pre | Post | Pre | Post |
| Barry, S3 | Correct | Correct | Correct | Correct | Wrong | Correct |
| Judith, S4 | Wrong | Correct | Wrong | Correct | Wrong | Correct |

Table 7.13. Pair S3, S4, predictions.

Barry got two out of three predictions correct in the pre test and did improve after the interaction (all predictions correct). He did not provide an explanation of conservation laws in the pre test, he only gave an example which was naive and inappropriate: *"if cow eats grass some energy is transferred to the cow"* (MM, Q1, S3, p4). In the post test he gave a more appropriate explanation. A notable pre to post test difference is that while his answers were only factual in the pre test, in the post test, as well as predicting directions of movement, he carefully explained the outcome using the conservation laws. For instance, in prediction 2 he predicted: *"Small mass will rebound backwards"* (MM, Q1, S3, p8) in the pre test, and *"it will bounce off it losing some of its speed, through energy passed over to the immobile mass and moving it slightly"* (MM, Q1, S3, p8) in the post test. His third post test prediction was that *"the large mass will slow down and the small mass will move off quite fast"* (MM, Q1, S3, p9), which is rather vague in its use of qualitative terms *"quite fast"* and *"slow"*

down", but is nearer a correct explanation than his pre test prediction: *"It will stop or rebound not as far"* (MM, Q1, S3, p9).

Judith's answers in the pre test and post test on the meaning of conservation laws consisted of similar statements on the conservation of energy. She got all three predictions wrong in the pre test but improved considerably in the post test (all three predictions correct). Her pre test predictions followed a consistent pattern, that of one or both masses stopping after the collision, and there was no mention of the direction in which the other mass would move post collision. Her second and third pre test predictions were identical statements, only alternating the size of the masses, e.g. prediction 2, pre test: *"If total energy change is completed then the small mass will be stationary and the large mass will have a small velocity"* (MM, Q1, S4, p8) and prediction 3, pre test: *"If total energy change is completed the big mass will be stationary and the small mass will have a large velocity"* (MM, Q1, S4, p8).

| Time | Student activity | Comment |
|------|---|--|
| 0.00 | Try various options on the screen to work out what the CD-ROM is about and how to use it. | |
| 0.02 | Collision 1. Collect data for task 1 (4 points). | Are not sure about the number of points they need to get readable graphs of data. |
| 0.04 | Measure the velocity for mass one before the collision from the velocity graph. | Go straight to the graphs without looking at the spreadsheets. |
| 0.05 | Plot some more points and go back to the velocity graph. | |
| 0.06 | Plot points on the second mass. | Predict that the velocity will be the same as there is no friction. |
| 0.08 | Examine graphs of acceleration and velocity. | Discuss why the second velocity is less than predicted. |
| 0.10 | | Agree that both momentum and kinetic energy "will be passed on". |
| 0.13 | Collision 4. Plot points on the blue mass movement. | Examine the graphs (mainly v_x). |
| 0.15 | Calculate momentum and kinetic energy before and after the collision for the blue mass. | |
| 0.17 | Plot points for the green mass. | Plot a much bigger number of points than in their previous efforts. |
| 0.18 | Examine graphs of v_x and a_x . | Find v_x and a_x graphs difficult to read. Decide to plot the points again. |
| 0.20 | Plot point for the green mass for a second time. | |
| 0.23 | Examine v_x and a_x graphs. | |
| 0.24 | Examine the spreadsheet. | Try to use the spreadsheet since they do not understand scattered data on the graphs. |
| 0.26 | Calculate momenta before and after. | |
| 0.29 | Collision 5. Plot points for third task. | Try to deduct some relationship between the masses by working on the momentum definition of mass times velocity. |
| 0.30 | Examine a_x , a_y , v_x , v_y graphs. | |
| 0.32 | Calculate momenta before and after the collision. | |
| 0.34 | | Discuss what they have done so far to complete the task. |
| 0.42 | | Conclude their interaction by thinking aloud on the proportionalities in the momentum definition. |

Table 7.14. Observation schedule of students S3: Barry, and S4: Judith.

Barry and Judith briefly discussed the control of the mouse and the keyboard. It was decided that Barry would operate the mouse. After a short introduction to the functions of MM, they watched the first sequence three times. They went straight to the graph facility, examining the graphs of velocity and position. Their tactic was to identify on the graph the point of impact and write down the values for the velocity before and after the collision. In the first task they did not attempt to explain any discrepancies between the measured value of velocities and the expected one, ignoring them as acceptable experimental losses (Transcript 7.4).

S3. Graph of the velocity. You cannot get complete energy transfer, because it's still an air track.

S4. You have also air resistance, haven't you?

[They examine the acceleration graph].

S3. What's that?

S4. I don't know.

S3. It's reasonably constant. Slightly under 1.5m/s.

S4. The other one was just above, wasn't it?

S4. Just under 1.5 should be the thing to say.

S3. It is 1.25m/s.

S4. 1.3.

S3. It's supposed to be 1.5 though.

Transcript 7.4.

(MM, T, S3-S4, p28)

They had difficulties in comprehending the acceleration graphs which in the end they ignored. For the second task, their data indicated that the velocity of the projectile mass after the collision was slightly

smaller than its initial velocity. This resulted in a brief discussion where they wondered if the conservation of momentum and energy is obeyed in the sequence. Barry was willing to attribute it to an experimental error and ignore the discrepancy but Judith disagreed. They ended up discussing how the conservation laws applied to this case, as the following except shows (Transcript 7.5).

S4. If we work out the momentum before and after the collision, m_1v_1 equals, no... There should be a change in velocity of the blue one because it has a smaller momentum and it gives something to the green one.

S3. This velocity plus this velocity should equal the original velocity of the blue.

S4. The original momentum, because you have to account for the mass... Something like that.

Transcript 7.5.

(MM, T, S3-S4, p29)

In task three they attempted to find a relation of velocities of the gliders, but all they managed to do was to express proportionalities of masses thinking aloud on the momentum definition: momentum equals mass times velocity (Transcript 7.6).

S3. So we worked out that the mass and the velocity both affect the momentum, for if the mass is larger and the velocity stays the same, the momentum of the blue one afterwards is going to be greater....

S4. Despite the size it will have a larger velocity.

S3. ... and if the mass stays the same and the velocity is increased, this is going to be larger (blue one)... and if either of the two is increased... and this (the blue one) is gonna get smaller...

S4. Momentum is conserved despite... Momentum is affected by... mass and velocity, but it's constant.

- S3. We can say that momentum is proportional to velocity, can we say that?

S4. Of course we can say that.

S3. It's only proportional if the mass stays constant... and mass is proportional to momentum if the velocity stays constant.

S4. That will do.

Transcript 7.6.

(MM, T, S3-S4, p31)

Barry and Judith improved their predictions in the post test. They applied their knowledge of momentum and conservation principles to complete the tasks but they had difficulties in predicting how much energy or momentum is transferred in each collision. They kept quoting repeatedly the physics formalisms (e.g. definitions of momentum) when in perplexity about the solution to a task. They switched between the visual representation and the graph facility, almost ignoring the spreadsheets.

S9, S10: Roger and Ray.

The third pair of students, Roger and Ray, were 17 and 16 years old respectively. They were rated by their teacher: Roger as being of high ability and Ray as being less able but working hard.

| | Prediction 1 | | Prediction 2 | | Prediction 3 | |
|-----------|--------------|---------|--------------|---------|--------------|---------|
| | Pre | Post | Pre | Post | Pre | Post |
| Roger, S9 | Correct | Correct | Correct | Correct | Correct | Correct |
| Ray, S10 | Wrong | Wrong | Wrong | Wrong | Wrong | Correct |

Table 7.15. Pair S9, S10, predictions.

| Time | Student activity | Comment |
|--------|--|--|
| 14.10 | Collect 4 points in the first sequence. They observe the graphs of position and velocity. | Are not sure how many points are sufficient for the data collection. |
| 14.15. | Collect some more points. They go back to the graphs. | Slight loss of momentum. They decide that the kinetic energy is transferred, though there is a slight loss through friction and sound. |
| 14.20 | Second task. Collect data for each of the masses. Calculate average velocity for each of them. | Do not particularly appreciate the relation of graphs and spreadsheets, they hardly use the graphs. |
| 14.31 | Calculate $1/2mv^2$ to find what happens to the kinetic energy. | They try to find reasons for slight loss. |
| 14.50 | (Third task) Negotiate the velocity changes. | $(m_2/m_1) \times$ velocity of the first. |
| 14.55 | | Write up conclusions in worksheet. |

Table 7.16. Observation schedule of students S9: Roger and S10: Ray.

Both students gave satisfactory explanations of conservation laws providing relevant examples. Roger repeated in the post test his pre test answer of how the general expression of a conservation law applies to energy and momentum. Ray gave a general description of a conservation law in the pre test with an example (momentum) and in the post test a less vague definition of how energy can be changed from one form to another by being transferred between objects, using the same example.

Roger fared very well both in the pre test and the post test (all predictions correct in the pre and post test). In his first and second prediction there was a notable difference between his pre and post test responses. This was that in the latter except for predicting correctly the motion of the masses after the collision (*"The smaller mass would rebound away from the larger mass"*, MM, Q1, S9, p8), he also attempted some qualitative estimate of their velocity: *"but slower*

than its initial velocity" (MM, Q1, S9, p9). In his third prediction he provided an accurate prediction of the masses' motion.

Ray fared rather poorly in the pre test (all predictions wrong) and only one of his predictions was correct in the post test. In the first prediction he suggested that the two equal masses *"will end up stationary"* (MM, Q1, S10, p7) after the collision. He used a consistent but faulty model to predict that mobile masses stop after the collision and in the case of immobile masses taking part in the collision, all their momentum is transmitted to the immobile masses, concluding that *"The smaller mass will move at a speed faster than the initial speed of the larger mass"* (MM, Q1, S10, p10).

He also assumed that all collisions were *"inelastic"* (MM, Q1, S10, p10), but indicated that he was not sure about the distinction between elastic and inelastic ones. In his post test answers he did not make any prediction about the movement of the masses after the collision, he only gave a quantitative relation on their velocities, which he picked from Roger.

Roger's and Ray's strategy was to click on the gliders immediately before and after the collision, so that the spreadsheet would show the change of velocity. The frame by frame examination of the motion guided them in choosing points they considered appropriate. In the following excerpt they tried to find in the video sequence the exact point of collision and at which point exactly the gliders separate after collision (Transcript 7.7).

S9. They actually collided there.

S10. They haven't collided. Have they? They haven't quite touched.

Transcript 7.7.

(MM, T, S9-S10, p32)

They were also quite meticulous in their choice of appropriate values from the spreadsheets. For instance in their measurements of post collision velocities they realised that the instances of velocity they had collected corresponded to the masses still being in contact: *"They are slightly in contact there. They are still in contact in the first reading. So we will have to ignore the first reading"* (MM, T, S9-S10, p34).

In the first task they attributed the slight difference of velocities pre and post collision to friction (Transcript 7.8).

S9. Momentum is conserved, isn't it? There is a slight loss, because of friction.

S10. And air resistance?

S9. Air resistance shouldn't cause much of a problem, but there may be some kind of affection (sic) which accounts for 0.8m/s.

S10. Kinetic energy is just transferred. Isn't it?

S9. Kinetic energy is transferred from first to second. There may be a slight loss through sound.

Transcript 7.8.

(MM, T, S9-S10, p32)

Roger attempted to make sense of the third task rephrasing it from "how the speed of the immobile glider after the collision depends on the speed of the moving mass before it" to *"It's asking how the speed of the large one gives energy to the smaller one"* (MM, T, S9-S10, p35), which was a step to the correct direction. In the end they came up with

a quantitative general relationship between the masses and velocities, to which Roger was the main contributor. Though not scientifically correct it was an interesting attempt to generalise the MM sequences into an abstract mathematical formula, using the conservation laws: *“for the relationship of masses the change in velocity of the second glider will be in the relationship of Mass of first glider over Mass of second glider, times velocity change of first glider”* (MM, W, S10, p18).

Roger and Ray were a heterogeneous couple in terms of ability. Ray was not happy working with Roger and did not improve his predictions in the post test. In their explanations they used mostly the linear/causal model (Whitelock *et al*, 1993a) to explain collisions, talking about *“coming in and pushed out”* colliding gliders (MM, T, S9-S10, p37). Their attempts to transform these instances of interacting gliders into relationships of masses and velocities, ended up in an inaccurate though not altogether incorrect relationship of velocities and masses, where they took into account the conservation law and its derivatives. They attributed untidy data, e.g. points out of the predicted sequence in the graphs, to erratic clickings on the data collecting frame: *“It’s only because you are moving up and down, when you click on a point out of line”* (MM, T, S9-S10, p32).

They used both spreadsheets and graphs and examined with great attention each sequence frame by frame, choosing points they considered appropriate and also appropriate values from spreadsheets and graphs. They negotiated in an environment with the “feel” of the real world, consequently friction and loss of kinetic energy were an unsurprising occurrence to them.

7.3.3. Observational data

The participants of this study were able to manipulate the interface without any difficulty. They were familiar with the Windows 3.1. environment, where MM runs, since they had all used Windows before. The majority were also quite competent in navigating the interface, switching between the graph and spreadsheet facilities of the program.

Some of them realised early during the data collection that the way the data is collected contributes to successful results, exactly like a careful data collection in a physics lab would result in better results and easier to interpret graphs; also that there were more and less appropriate points on the masses on the screen for getting a *"nice set of data"* (MM, Q2, S8, p20) and that any displacement of the original chosen point can *"mess up"* (MM, Q2, S2, p20), i.e. produce quite big fluctuations on the graphs (Transcript 7.9).

S10. What about this 0.7?

S9. It's only because you are moving up and down, when you click on a point out of line.

S10. OK.

S9. Do you want to take some more readings or should 5 be enough? Let's take five to make it more accurate since it doesn't take long.

Transcript 7.9.

(MM, T, S9-S10, p32)

However, it did not become explicit in their interaction that a minimum number of clicks was necessary to produce velocity and acceleration graphs. It also did not become explicit from their

performance that they realised the existing close relation between well chosen clicks on the screen for collecting data which would translate into easy to read graphs (Transcript 7.10).

S4. Are 4 points enough?

[They switch to the graphs].

S3. This is time and distance. So it is moving at a constant velocity and then it stops. This is m/s. Velocity v_x , 1.5m/s... I'm not sure.

S4. Go back and plot some more points. This might give us an answer... OK.

[They plot some more points and then go back to the graph].

S4. It gives a better view, doesn't it?

S3. Yes, it does.

Transcript 7.10.

(MM, T, S3-S4, p27)

They mostly tried to investigate the physical principles by examining either the graphs of velocity or the spreadsheets of the collected data rather than a combination of the two. The ones that used the graphs had some difficulty in interpreting the graphs that their data produced.

A possible explanation for the lack of success in using the graphs in MM effectively could be that the students' experience of computer simulated experiments is usually of "sanitised" clear computer-generated results, whereas the realism of getting graphs, whose quality depended on the quality of the collected data, did not convince them as an alternative experience to the physics laboratory.

The system being open-ended demands an accuracy of measurements to make the collected data meaningful. Slight variations and mistakes in keeping the same point (i.e. the point the students choose for their measurements) result in data which do not clearly demonstrate relations between the chosen variables, especially when the variables are the velocity and the acceleration against time.

Very few of the students used the audio facility for getting information. The help facility giving textual information on the physics concepts was also used only by a small number of students.

7.4. Findings of the study

This section will examine how the MM interface facilitated the learners' interaction. It will also consider if and how aspects of MM related to fidelity, and complexity contributed to promoting learning.

The pre test showed that not all of the users had adequate knowledge on the context of MM. Before the interaction the majority did not positively distinguish between elastic and inelastic collisions. Also in their predictions on the motion of colliding masses they provided a wide spectrum of answers some of which were far from being scientifically acceptable. Their explanations were based either on the common sense definitions of scientific terms, or they ignored the generality of scientific laws by focusing only on their commonest instances. For example, their answers to what is meant by a conservation law were based either on the definition of the word "conserve" without elaborating, or they focused only on the commonest type of conservation law, the conservation of energy.

The interaction showed that MM had an impact on students' understanding, as the comparison between the pre and post interaction questionnaires showed. The quantitative comparison between the predictions showed a statistically significant difference between the total prediction scores. Another factor that supports the view of conceptual learning improvement is the qualitative comparison between the pre and post test predictions. The users' answers in the post test were carefully phrased from a "scientific" point of view and they used less abstract qualitative terms, like "slower" and "faster" in favour of more quantitative ones. After the interaction the students also had clearer ideas about the distinction between elastic and non elastic collisions.

The participants generally fared well in the first two tasks of the worksheet on investigating if the sequences obeyed conservation laws but the majority did not manage to make much progress on the third task (relation between the relative masses of the two gliders and the speed of the projectile mass after the collision). Most students were unable to relate the algebraic formalisms learned in the classroom to the description of a motion they observed. In some cases they came up with interesting though not scientifically correct suggestions concerning the solution of the problem.

The MM sequences were treated as real experiments. Any discrepancies from the conservation laws in most cases were attributed to experimental errors. The real life context representation in MM sometimes caused doubts as to whether it represented a frictionless environment or not. The MM's high fidelity interface

made the students forget the ideal Newtonian underlying model, so that they expected friction and reverted back to the complications of explaining phenomena in the real world. Some of the users argued that even in elastic collisions, some kind of energy was lost. They attributed it to: *"loss through heat and sound"* (MM, Q1, S8, p8) or to *"friction"* (MM, T, S1-S2, p25).

A drawback of the MM interface was that it was not always very clear in the motion of the masses when exactly they separated after collision. This complicated the choice of appropriate values for the velocity.

Most (2/3) of the students extracted the values they needed for calculations from the graphs of velocity and they hardly looked at the data spreadsheets. The graphs in MM are not synchronous and the absence of direct information, like digital counters of the values of variables of the participating masses made the students rely exclusively on the graphs for extracting physical knowledge. They had difficulties with the graph function and did not understand scattered data presented on the graphs, especially comprehending the acceleration graphs which in the end they ignored. The other 1/3 of the students used the spreadsheets and calculated averages of the values of the variables.

7.5. Conclusion

In this chapter findings obtained through the observation of students in the natural school setting, where the MM experiment was carried out, were presented and discussed.

Using MM proved to be a constructive activity for the students. The learners experimented and negotiated successfully on sequences of collisions. MM offered an interface which was realistic in terms of visual representation and behaviour and non ambiguous as it did not use any idealisations. The interface used real time and the underlying model was of low complexity. The manner of data collection by the users, clicking points on the colliding gliders, which was quite close to some equivalent practices in the physics lab enhanced its fidelity.

It appears that the participants felt they were working in a Newtonian environment with the “feel” of the real world, consequently the influence of friction and loss of kinetic energy were an unsurprising occurrence to them. The majority switched between the visual representation and the graph facility, almost ignoring the spreadsheets.

The next chapter describes interactions with another interactive learning environment: CirclesColliding, simulations which were designed to represent another combination, the use of idealisations and visual simplicity in the interface and low complexity in the underlying model.

Chapter Eight

The CirclesColliding study: working with a low fidelity, low complexity simulation

8.1. Introduction

The chapter describes observations with learners using the CirclesColliding (CC) simulations. After an outline of the procedure, there is a description of the structure of the study (aims, subjects and procedure). This is followed by an analysis of the questionnaires and video taped data of the actual interaction. The key findings are given and it is shown how these relate to the main strands of this research.

8.2. The Study

8.2.1. Subjects and procedure

Twelve A level students, median age 17, worked in a real school setting in Milton Keynes and London. The main factor in determining the pairing of the students was whether the subjects were available to participate in the experiment (see section 7.2.1). They formed both single sex and mixed gender dyads; in proportions shown by table 8.1:

| | |
|----------------------|--------------------|
| Single sex dyads: 5; | Female: 1, Male: 4 |
| Mixed dyads: 1 | |

Table 8.1. Gender distribution in participating students.

Data was collected by observing students interacting with the simulation. Their interaction was video-taped and their protocols transcribed. The outcomes of the experiment (pre and post test questionnaires and videotapes) were examined in relation to conceptual shifts between pre test and post test, problem solving strategies they used to carry out the tasks, and their performance.

The students worked for two hours approximately:

- (i) Reasoning without the computer by answering a questionnaire and pre test. In the pre test, they were asked to predict the outcome of three collisions, as with MM (Chapter Seven) simulations (20 mins).
- (ii) Interacting with the simulation. The students completed a number of tasks running the simulation sequences and examining graphs and digital counters in order to complete a work-sheet (60 mins approximately).
- (iii) Repeating the pre-interaction questionnaire and completing a questionnaire on usability (around 10-15 mins)
- (iv) Participating in post-interaction interviews which aimed to pick up on any areas noted as being interesting while they were working with the simulation (10-15 mins).

8.2.2. The CC1 sequences

The CirclesColliding1 (CC1) simulation sequences that were used are simulations of collisions, objects moving on the screen and undergoing linear collisions (the motion of the objects is in the same straight line taking into account one dimensional collisions only, not dealing with the vectorial nature of linear momentum) with other objects.

CC1 represents an environment with low fidelity (idealised animated objects) and low complexity (simple underlying model, linear collisions, where the outcome is determined only by the mass and the x components of the speeds).

Specifically there is:

- an elastic collision where an object (10kg) collides with another object of the same mass (Collision 1), Fig. 8.1.
- a moving light (2kg) object which undergoes an elastic collision with a heavier stationary one (8kg), (Collision 2) Fig. 8.2.

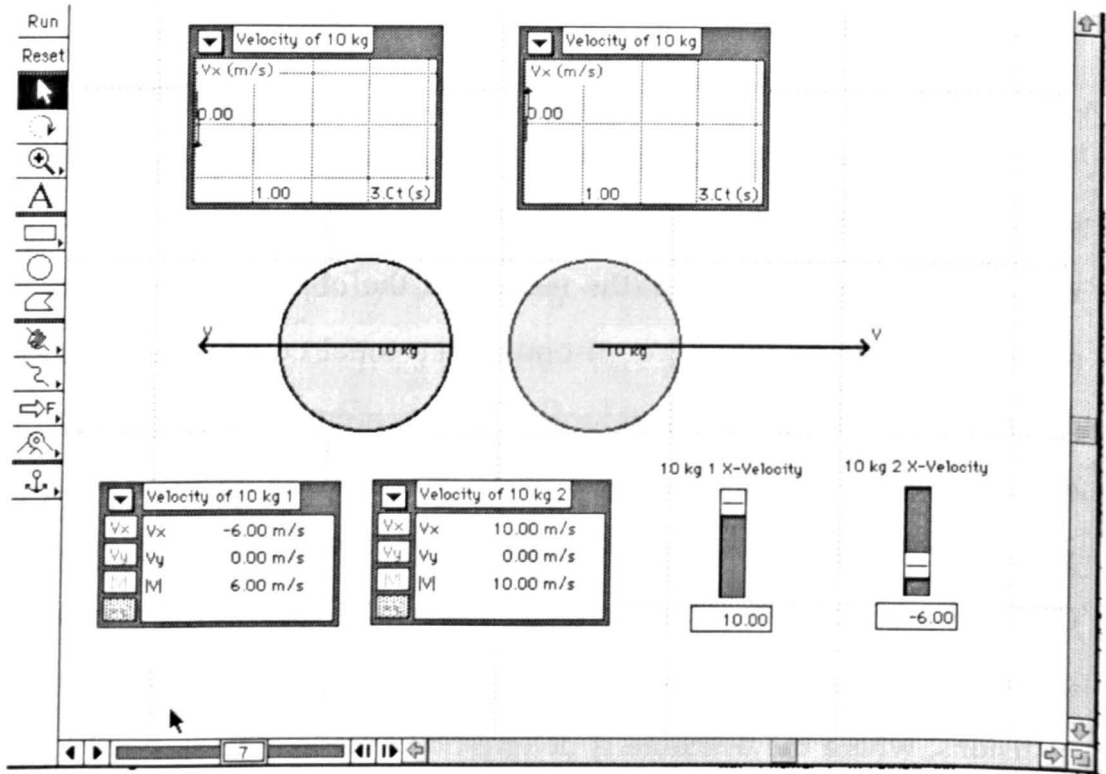


Fig. 8.1. CC1 (Collision 1).

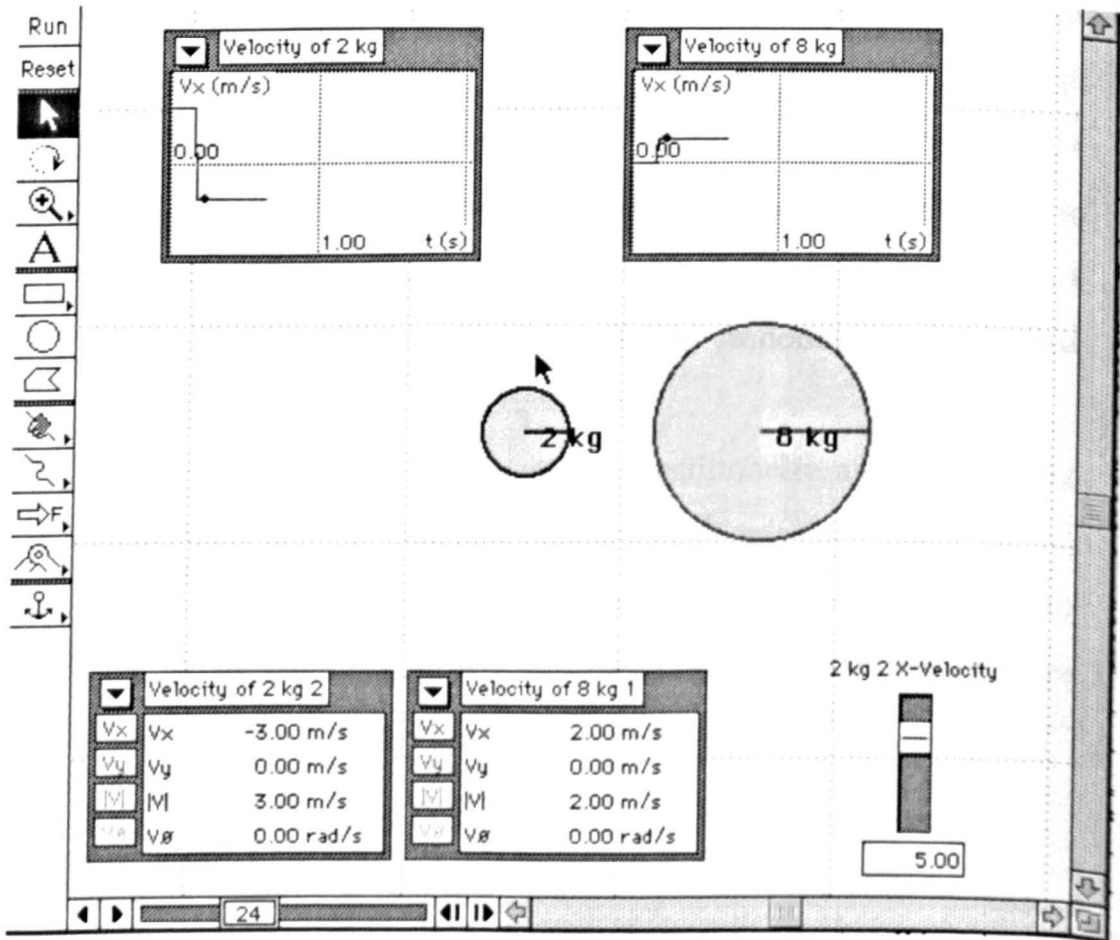


Fig. 8.2. CC1 (Collision 2).

- a moving object (10kg) which has an elastic collision with a lighter (2kg) stationary one, Fig. 8.3 (Collision 3).

8.2.3. Description of the worksheet: the tasks

All subjects were asked to complete 3 tasks, while interacting with CC1. These tasks were based on the 3 CC1 sequences. The tasks were posed in order of difficulty and were as follows (see also 6.2.4):

Collision 1: Explore the sequence and see if you can measure the velocities of the objects before and after a collision. What might

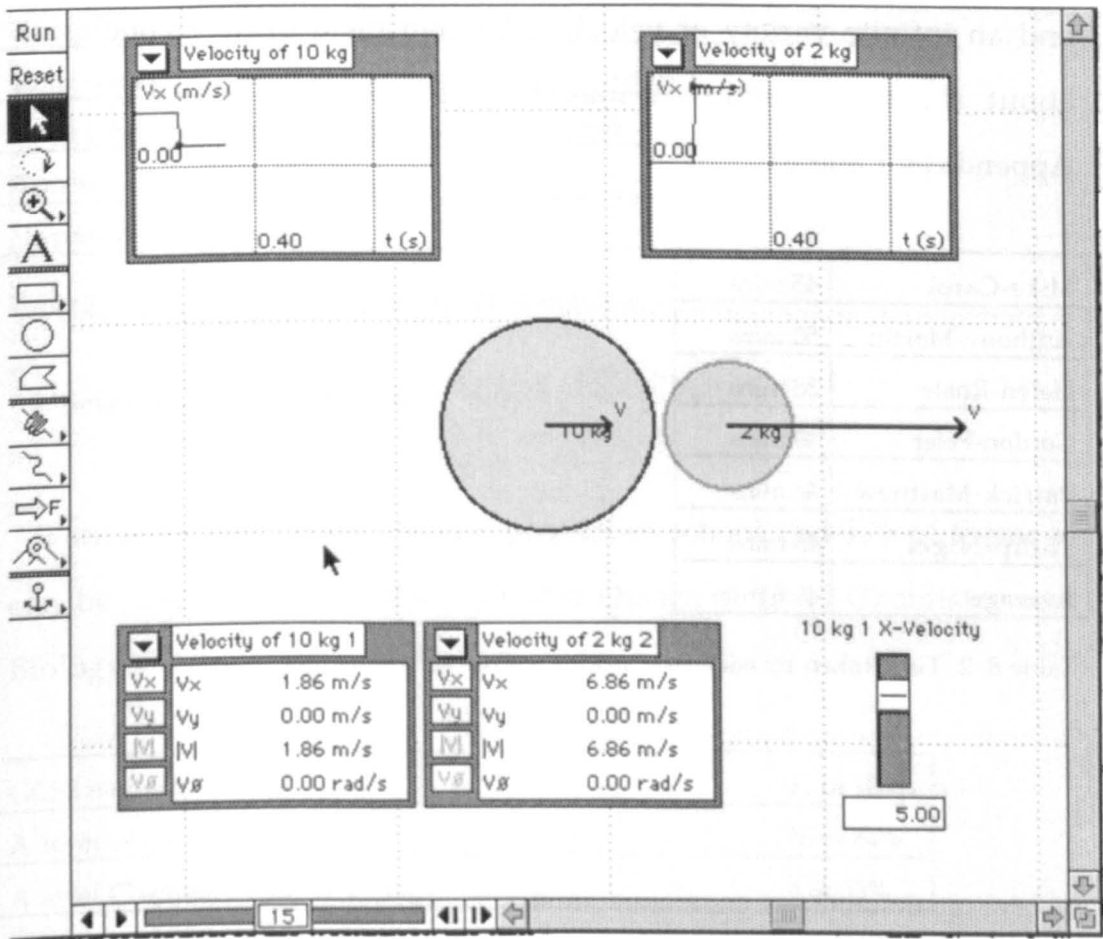


Fig. 8.3. CC1 (Collision 3).

happen to both momentum and kinetic energy in this kind of collision?

Collision 2: Use the sequence to measure how the momentum and kinetic energy of the two masses change in the collision.

Collisions 1, 2 and 3: Try making measurements that will help you decide how the speed of the immobile mass (target) after the collision depends on the speed of the other one (projectile) before it and how it depends on their relative masses.

In this task they were asked to combine information and data from all three sequences. They had a variety of masses (three combinations) and an infinite variety of velocities to help them draw a conclusion about the relationship of masses and velocities (see 7.2.3 and Appendices 1 and 6).

| | |
|-----------------|-----------|
| Mike-Carol | 45 mins |
| Anthony-Martin | 50 mins |
| Helen-Rosie | 38 mins |
| Gordon-Peter | 49 mins |
| Patrick-Matthew | 46 mins |
| Philip-Nigel | 45 mins |
| Average | 45.5 mins |

Table 8. 2. Time taken by each pair working with the simulation.

8.3. Data analysis

8.3.1. Questionnaire analysis

Previous experience with computers

Before each session the students filled out a questionnaire on their experience of using computers, as with MM, Chapter Seven. Their experience was mainly of using the school computers (word processing and spreadsheets) but some of them had also explored multimedia environments. This is summarised in the table below (Table 8.3).

| | |
|---|-----------|
| Using school computers: word processing, spreadsheets | 10 or 83% |
| Using school computers: multimedia, data logging | 2 or 17% |
| Games | 1 or 8% |
| No previous experience | 2 or 17% |

Table 8.3. CC1: Previous experience with computers.

Science courses in school

All students had chosen A level physics in school and 1/3 of them, as can be seen from table 8.4, had also chosen A level Chemistry and Biology.

| | |
|----------------------------------|------------|
| GCSE modular science | 12 or 100% |
| A level physics | 10 or 84% |
| A level Chemistry and/or Biology | 4 or 33% |

Table 8.4. CC1: Science courses in school.

Mathematics courses in school

Information was obtained from the teacher regarding the courses in Mathematics the students the students had done (GCSE) or were doing (A level Maths), table 8.5.

| | |
|---------------|------------|
| GCSE Maths | 12 or 100% |
| A level Maths | 5 or 42% |

Table 8.5. CC: Mathematics courses in school.

Previous knowledge of simulations

Another part of the questionnaire investigated their previous knowledge on the nature of a computer simulation. The range of the students’ previous experience with computer simulations is given in the table below (Table 8.6):

| | |
|--|----------|
| I have never used a computer simulation | 9 or 75% |
| I have used a computer simulation before | 3 or 25% |
| I don’t know | 0 |

Table 8.6. CC: Previous knowledge of simulations.

Pre and post test comparisons

In the second part of the pre test questionnaire the students’ initial knowledge on collisions was tested (as in the MM study, Chapter Seven). They were first asked to answer a question on the meaning of conservation laws:

- What is meant by a conservation law? Can you give any further examples of conservation laws?

The subjects were then pretested with a questionnaire which was based on Whitelock et al (1993a), Appendix 1. Students were asked to predict the subsequent motion of masses after collision for 3 conditions (exactly as in the MM study, see 7.3.1).

In the post test all three questions were repeated. Table 8.7 shows all the participating students' pre and post test predictions:

| Students | Prediction 1 | | Prediction 2 | | Prediction 3 | |
|--------------|--------------|---------|--------------|---------|--------------|---------|
| | Pre | Post | Pre | Post | Pre | Post |
| Mike, S13 | Correct | Correct | Correct | Correct | Correct | Correct |
| Carol, S14 | Correct | Correct | Correct | Correct | Wrong | Correct |
| Anthony, S15 | Wrong | Correct | Wrong | Wrong | Wrong | Wrong |
| Martin, S16 | Correct | Correct | Correct | Correct | Correct | Correct |
| Helen, S17 | Wrong | Wrong | Wrong | Wrong | Wrong | Correct |
| Rosie, S18 | Correct | Correct | Wrong | Wrong | Wrong | Wrong |
| Gordon, S19 | Correct | Correct | Wrong | Correct | Correct | Correct |
| Peter, S20 | Correct | Correct | Correct | Correct | Wrong | Correct |
| Patrick, S21 | Correct | Correct | Wrong | Wrong | Wrong | Correct |
| Matthew, S22 | Wrong | Correct | Correct | Correct | Wrong | Correct |
| Philip, S23 | Correct | Correct | Correct | Correct | Correct | Correct |
| Nigel, S24 | Wrong | Correct | Wrong | Correct | Correct | Wrong |

Table 8.7. CC1 pre to post test shift.

A comparison between the pre and post interaction tests showed that there was an increase in correct predictions which indicated a shift in students’ conceptual understanding concerning the tested conditions. The average percentage scores of the pre test and post test answers were as follows:

| CC1 | Prediction 1 | Prediction 2 | Prediction 3 |
|-----------|--------------|--------------|--------------|
| Pre test | 66% | 50% | 42% |
| Post test | 92% | 66% | 75% |

Table 8.8. CC1, Preliminary and post test: Percentage of correct answers.

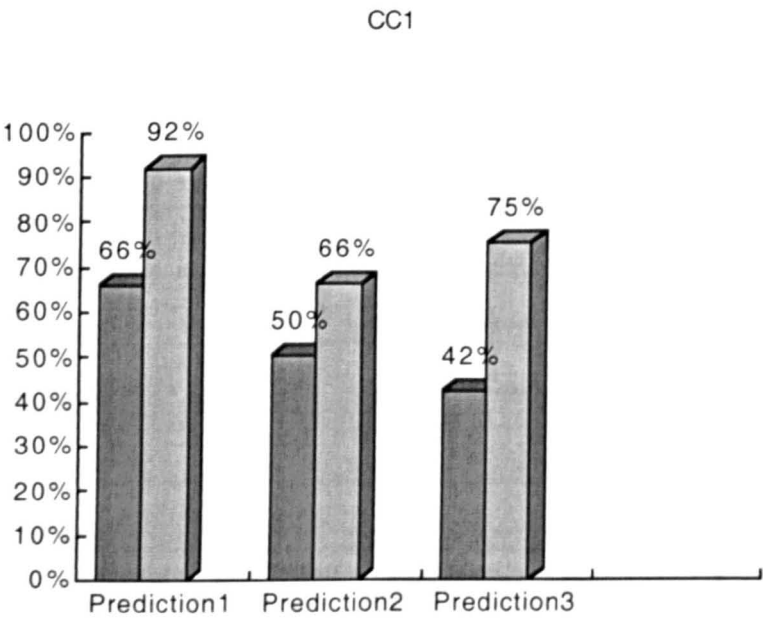


Fig. 8.4. Pre to post test percentages of correct answers.

A one-tailed Wilcoxon signed-ranked test was carried out to see if there was a significant difference between the pre and post test means of the total predictions scores. The result of the Wilcoxon test (Table 8.9) showed that there was a significant difference between the pre and post test total prediction scores ($T=0$; $n=8$; $p<0.05$).

| Student | Pre Test | Post Test | Sign of difference | Size of difference | Rank of difference |
|---------|----------|-----------|--------------------|--------------------|--------------------|
| S13 | 3 | 3 | | 0 | |
| S14 | 2 | 3 | - | 1 | 4 |
| S15 | 0 | 1 | - | 1 | 4 |
| S16 | 3 | 3 | | 0 | |
| S17 | 0 | 1 | - | 1 | 4 |
| S18 | 1 | 1 | | 0 | |
| S19 | 2 | 3 | - | 1 | 4 |
| S20 | 2 | 3 | - | 1 | 4 |
| S21 | 1 | 2 | - | 1 | 4 |
| S22 | 1 | 3 | - | 2 | 8 |
| S23 | 3 | 3 | | 0 | |
| S24 | 1 | 2 | - | 1 | 4 |

$\sum R_{-} = 36$

$\sum R_{+} = 0$

Table 8.9. Wilcoxon test for CC1.

A statistical analysis using McNemar’s test (binomial) was also carried out, as with MM and CoC (Table 8.10). The 12 subjects took part in the cross-over trial and the variable’s (the students prediction) two levels corresponded to the values “correct” and “wrong”. The test statistic was compared with a binomial distribution to determine the probabilities of the possible outcomes and to investigate its significance. There was no statistically significant improvement in any of the predictions. To further investigate the interactions, a selective analysis of the pairs’ sessions in front of the computer was attempted with a qualitative assessment of the interaction.

CC1

| | | Post test | | |
|----------|--------------|-----------|-------|-------|
| Pre test | Prediction 1 | Correct | Wrong | Total |
| | Correct | 8 | 0 | 8 |
| | Wrong | 3 | 1 | 4 |
| | Total | 11 | 1 | 12 |

McNemar’s test, df=1 (binomial), p=0.2500.

| | | Post test | | |
|----------|--------------|-----------|-------|-------|
| Pre test | Prediction 2 | Correct | Wrong | Total |
| | Correct | 6 | 0 | 6 |
| | Wrong | 2 | 4 | 6 |
| | Total | 8 | 4 | 12 |

McNemar’s test, df=1 (binomial), p=0.5000.

| | | Post test | | |
|----------|--------------|-----------|-------|-------|
| Pre test | Prediction 3 | Correct | Wrong | Total |
| | Correct | 4 | 1 | 5 |
| | Wrong | 5 | 2 | 7 |
| | Total | 9 | 3 | 12 |

McNemar’s test, df=1 (binomial), p=0.2188.

Table 8.10. CC1: McNemar’s test.

8.3.2. Discussion of pairs, pre to post gain and interaction

In the following sections each pair is described in general terms giving their age and ability ratings. The students’ pre to post test gain is also shown. Then an account of their interaction with the simulation is given. This description is based on the video taped interaction while the pairs of students were carrying out the tasks of the worksheets. Three out of the six pairs were chosen selectively to cover representative styles of strategies and interactions. The aim in this kind of analysis was to find common characteristics and strands. The criteria for selecting these three pairs for analysis were the difficulty or

ease with which they completed the tasks and the inclusion of different interaction styles which revealed possible implications for the simulation’s complexity and fidelity. Also a major complementary consideration was the pre to post test gain. One pair of students was chosen who did not achieve overall pre to post prediction gain and another one who did well. The third one was chosen as in their predictions there was the only occurrence of a pre test Correct to post test Wrong in the main study. In the transcripts an effort was made to include all significant remarks, comments and bits of dialogue.

S15, S16: Martin and Anthony

The first pair of students Martin and Anthony are 17 years old. Martin was rated by his teacher as of high ability and Anthony of medium.

| | Prediction 1 | | Prediction 2 | | Prediction 3 | |
|--------------|--------------|---------|--------------|---------|--------------|---------|
| | Pre | Post | Pre | Post | Pre | Post |
| Anthony, S15 | Wrong | Correct | Wrong | Wrong | Wrong | Wrong |
| Martin, S16 | Correct | Correct | Correct | Correct | Correct | Correct |

Table 8.11. Pair S15: Anthony, S16: Martin pre and post test predictions.

Anthony got all three predictions wrong in the pretest and one prediction correct after the interaction. He provided acceptable explanations on the meaning of a conservation law both in the pre test (*"A law describing how a property is conserved e.g. conservation of energy or momentum."* (CC1, Q1, S15, p5)), adding in the post test that *"conservation laws often apply to collisions of objects"* (CC1, Q1, S15, p5), thus contextualising his explanation But his predictions were either vague or incorrect, providing, for instance, two contradictory

alternatives for the second prediction: *"The small mass will have lost energy but may bounce back. It should stop, transferring all energy however."* (CC1, Q1, S15, p9).

Martin gave sensible explanations of what a conservation law is and got all three predictions correct both in the pre test and the post test. However, it could be argued that his responses in the post test were qualitatively different from those of the pre test. In the first post test answer he used the term momentum instead of speed and talked about signed momenta, a result probably of the interaction, where he worked with conservation laws and calculated momenta. In his second and third post test predictions he included a statement which did not exist in his pre test responses, about how *"the difference in their velocities is equal to the original velocity of the larger mass"* (CC1, Q1, S16, p9), thus using the conclusion about the relation of velocities he had reached in the end of his interaction with the simulation.

Martin and Anthony talked together throughout the interaction. They watched each sequence a few times (e.g. they watched the first sequence twice using two different settings for the velocity variables) and then frame by frame before they attempted to give any answers.

| Time | Student activity | Comment |
|-------|--|---|
| 00.00 | Watch the first sequence (equal masses) (1). | |
| 00.05 | Change the velocities (2). | Watch the sequence a few times and then frame by frame. |
| 00.10 | Look at digital counters. Write down their measurements. | Calculate momentum before and after. |
| 00.15 | | Conclude that momentum and K.E are conserved. |
| 00.16 | Watch the second sequence (unequal masses) (3). | |
| 00.20 | Change the velocities and watch the sequence again (4,5). | Discuss the conservation of momentum in this sequence. Calculate total momentum and kinetic energy and conclude that they are both conserved. |
| 00.30 | Third task of the worksheet. Watch first the second and then the third sequence (6,7). | |
| 00.35 | | Discuss a possible relationship of the speeds which could be related to that of the masses. |
| 00.45 | Watch again sequences 1 and 2 (8, 9,10,11). Vary the velocities putting a few characteristic values (10, 5 and 1). | Do not reach a final agreement on what kind of relationship of velocities would be an answer to the task. |
| 00.50 | | Write up their conclusions in the worksheet. |

Table 8.12. Observation schedule of students S15: Anthony and S16: Martin.

The first two tasks referred to two instances of collisions: equal masses moving at the same speed and a small mass which collides with a much bigger immobile mass. They easily reached an agreement on what should be a correct answer to the investigation (whether the masses’ behaviour complied with the conservation laws), by calculating momenta and kinetic energy, as the following excerpt for task 1 shows (Transcript 8.1).

S15. Right. This is going down here (Right slider). How much? Five?

S16. Let’s stop it.

S15. Let’s go back

[They look at the sequence again frame by frame.]

S15: Let's go to see their velocities, just before the collision. Where we have ten and five.

S16. After the collision they swap over. That's ten and that's five.

S15. Kinetic energy and momentum. Are they conserved?

S16. They must be. It's the same mass and momentum overall is conserved.

S15. Do we need to elaborate on that?

Transcript 8.1.

(CC1, T, S15- S16, p27)

The third task of the worksheet asked them to use the CC1 sequences to find a generalised relationship on the collision between a projectile and a target. After watching the sequences a few times, varying velocities, Martin suggested a mathematical relation describing how the velocities change after the collision (63% of the velocity of the projectile is transferred to the target). They attempted to generalise this relationship, by transferring it first to the relation of momenta and then to the relation of the masses. The quote below follows their attempt to complete the third task (Transcript 8.2).

S15. Let's run it. Stop it there... After the collision it's ten more. Let's change it. This was half of the last one. We halve the initial velocity and that halves the difference in speed. Does it?

S16. No... It will be a square relationship... maybe. Energy is conserved, mass is the same. I don't know, I'm just improvising.

S15. Let's reset once more.... It's always 37% of the initial velocity, when the mass of the first object is 5 times that of the smaller.

S16. That's the initial velocity but what 37 has got to do with it?

S15. Well?

S16. How does this one relate to the mass?

Transcript 8.2.

(CC1, T, S15- S16, p29)

They did not reach any final agreement on what relationship of velocities would be an appropriate answer. They did not manage to move away from making repetitive quantitative comments on the results of their calculations, quoting repeatedly physics formalisms (calculations of momentum), to meet the specific requirements of the problem. Anthony had difficulties following Martin's initiatives. They discarded graphical representation as not essential, and they used the counters' values for calculations (Transcript 8.3).

S16. [Looking at the bar graphs]. Is this the same?

S15. The only difference is that you look at bars instead of numbers to find how much it represents, the actual figure.

S16. It's looking nice though.

S15. Just looking is not what we need right now.

Transcript 8.3.

(CC1, T, S15- S16, p29,30)

Martin and Anthony worked methodically for the first two tasks using the interface's functions (controls and digital counters), suggesting sensible techniques for completing the tasks. They seemed to be attentive to the features of the interface, with which they familiarised themselves very quickly, by making proper use of the simulation: they experimented with different values of velocities though quite randomly. Throughout their interaction they ignored

the graph facility and relied on the counters for following the velocity variations.

S19, S20: Gordon and Peter

The second pair of students, Peter and Gordon, are 17 years old. They were both rated as having medium ability by their teacher.

| | Prediction 1 | | Prediction 2 | | Prediction 3 | |
|-------------|--------------|---------|--------------|---------|--------------|---------|
| | Pre | Post | Pre | Post | Pre | Post |
| Gordon, S19 | Correct | Correct | Wrong | Correct | Correct | Correct |
| Peter, S20 | Correct | Correct | Correct | Correct | Wrong | Correct |

Table 8.13. Pair S19 S20, predictions.

Gordon got one out of three predictions wrong in the pretest and improved after the interaction (all predictions correct). His second pre test prediction was wrong stating that post collision *"the larger mass will stay still"* (CC1, Q1, S19, p9). He improved in the post test, this time indicating that *"the smaller mass will bounce off the larger mass"* (CC1, Q1, S19, p9) and making a reference to the outcome of the impact on the second mass: *"but it will transfer some of its momentum to the larger mass"* (CC1, Q1, S19, p10). He could not explain the meaning of a conservation law in the pre test and his explanation in the post test was relevant to the simulation's context: *"Energy is conserved in a collision and so is momentum"* (CC1, Q1, S19, p5).

Peter gave sensible explanations of a conservation law both in the pre test and the post test. He got one out of three predictions wrong in the

| Time | Student activity | Comment |
|-------|--|--|
| 00.00 | Watch the first sequence (1) | |
| 00.03 | Change the velocities (2) | Try to understand how the change of velocities affects the motion of the masses. |
| 00.08 | Change the velocities and watch the sequence (3,4) | |
| 00.11 | Look at digital counters. Write down their measurements. | Use velocities before and after to calculate momentum before and after. |
| 00.14 | Change the velocities and watch the sequence (5,6,7,8,9,10,11) | End up with a conclusion on conservation of momentum and kinetic energy |
| 00.17 | Watch the second sequence (unequal masses) (12) | Express surprise that the big mass moves to the right after the collision |
| 00.19 | Change the velocities and watch the sequence (13,14,15) | |
| 00.24 | Change the velocities and watch the sequence (16) | Discuss the conservation of momentum in this sequence. Have doubts about their mathematical calculations and conclude that kinetic energy is conserved but momentum is not |
| 00.31 | Third task of the worksheet. Watch the second and third sequence (17,18,19,20) | |
| 00.40 | | Reach a quantitative relation between velocities but they do not find any relation of it with the masses. |
| 00.45 | Watch repeatedly the third sequence (21,22,23,24) | Conclude that neither momentum nor kinetic energy is totally conserved in the third case |
| 00.49 | | Write up their conclusions in the worksheet. |

Table 8.14. Observation schedule of students S19: Gordon and S20: Peter.

pre test and did improve after the interaction (all predictions correct). When asked to predict the effect of a big mass colliding with an immobile smaller mass, he predicted incorrectly that the masses “*will join together as one mass and move in the same direction that the big mass was travelling*” (CC1, Q1, S20, p12). In the post test he fared better by providing an accurate prediction “*The larger mass will considerably slow down but the small mass will move with a speed much quicker*”

(CC1, Q1, S20, p12) and also suggesting a relationship between the pre and post collision velocities of the projectile and the post collision velocity of the target.

After a very short introduction to the simulation Peter and Gordon watched the first sequence many times (11 times, each time changing randomly the velocities, including the case when one of the masses is immobile), trying to understand how the change of velocities affects the motion of the masses post collision. They easily calculated momentum and kinetic energy, concluding that *"in all these cases kinetic energy and momentum are conserved"* (CC1, W, S19, p16). The following excerpt follows their reasoning in completing task one (Transcript 8.4).

S19. That one adds speed to the other one which gets extra momentum.

[Look at digital counters. They write down their measurements].

S20. That's what happens. The momentum is conserved... Did you reset that?... That's the perfect elastic collision. Both the same mass, both the same velocity in the opposite direction.

S19. Yeah. In all these cases kinetic energy and momentum are conserved...

Transcript 8.4.

(CC1, T, S19-S20,p30)

However, they were surprised, when using the second sequence (small mass colliding with a bigger, immobile one), that the bigger mass moved to the right after the collision. They carefully watched the sequence five times before calculating total momentum and total kinetic energy. Their mathematical calculations with signed velocities

were wrong; consequently they could prove the conservation of kinetic energy but not that of momentum, which involved negative values of variables. They concluded that the collision was not perfectly elastic as the following excerpt shows (Transcript 8.5).

- S20. Kinetic energy is conserved. It's got negative velocity. I don't know...
- S19. Ten, it's going to bounce back, look.
- S20. Yeah....That's it. Do before and after, just as we did.
- S19. Before...
- S20. It's gonna bounce back.
- S19. Analyse the situation. It starts with 10m/s. This one then revs back away. It's - 6. That's 4.
- S20. What was the -6? so the total kinetic energy before and after is conserved. But is the momentum?
...Momentum is going this direction as well, isn't it?
- S20. Momentum is not conserved at all. Momentum is gonna be negative.
- S19. Yeah.
- S20. Unless you don't take into account the sign, which direction is going to.
- S20. It's not perfect elastic.
- S19. I suppose so.

Transcript 8.5.

(CC1, T, S19-S20,p31)

For the third task they watched the second and third sequence eight times, varying the velocities, each time. They calculated a correct quantitative relation between the velocities which was that "*the smaller mass will move $x\text{ms}^{-1}$ faster than the larger mass where x equals the velocity of the large mass at the beginning*" (CC1, Q1, S20,p12), but they did not relate it to the ratio of the masses. In the end

of the interaction they felt confident that they could calculate any combination of velocities for the target-projectile type of collision, based on the above relationship, provided they had the necessary data (Transcript 8.6).

S20. So if you know the velocity of the large glider before and after, you can work out the velocity of the small.

S19. Plus whatever.

S20. If you are told that, then you can work out the relationships.

Transcript 8.6.

(CC1, T, S19- S20, p32)

Gordon and Peter switched between calculations and observing the simulation sequences many times, varying velocities. They concentrated on the digital counters for extracting information, ignoring the graphs. They showed surprise when using the simulation the masses did not behave as expected. Despite having difficulties in examining conservation laws they reached a correct quantitative relationship among the velocities.

S23, S24: Philip and Nigel

The third pair of students, Philip and Nigel, are 17 and 18 years old respectively. Philip and Nigel were both rated as having high ability by the teacher.

Philip, in his definition of conservation law, limited his explanation to energy conservation, describing energy in efficiency terms (output equals input): *"energy is conserved when what you put in is what you get out"* (CC1, Q1, S23, p6). His answer was identical in the post test.

He fared very well in his predictions (all predictions correct in the pre and post test). His first pre test prediction, which was identical with the post test one, was not very clearly phrased, though it indicated correctly the directions of the masses post collision: *"They will separate at the same distance apart, going in the opposite direction they came"* (CC1, Q1, S23, p8). His second prediction was also correct, suggesting that *"the big mass will move a little to the right whereas the small mass will move a lot more to the left than the big mass did to the right"* (CC1, Q1, S23, p10). This was an adequate description of what happens to the masses in terms of direction and velocities after the collision but it lacked in expressing the conditions in a scientifically acceptable way. In his post test answer he moved from this qualitative statement to a semi-qualitative one which not only gave the directions but commented on the velocities of the participant masses and their pre to post changes: *"The small mass will move to the left with a lower velocity, and the big mass will move to the right with a lower velocity compared with that of the small mass. Energy will be conserved, if none is lost to friction, sound."* (CC1, Q1, S23, p10). He also referred to kinetic energy and how it is conserved in a collision of this kind.

| | Prediction 1 | | Prediction 2 | | Prediction 3 | |
|-------------|--------------|---------|--------------|---------|--------------|---------|
| | Pre | Post | Pre | Post | Pre | Post |
| Philip, S23 | Correct | Correct | Correct | Correct | Correct | Correct |
| Nigel, S24 | Wrong | Correct | Wrong | Correct | Correct | Wrong |

Table 8.15. Pair S23,S24, predictions.

In his third prediction he also moved from a vague initial statement *"the big mass will only move a little to the right whereas the small mass will move a lot to the right"* (CC1, Q1, S23, p13) to one where the relationships of velocities were expressed better. So his pre test *"a little to the right"*, which referred to the distance covered by the big mass after the collision, had been changed to *"bigger mass will move with a lower velocity after the collision than it did before"* (CC1, Q1, S23, p13). Similarly the motion of the small mass *"a lot to the right"* was changed to, *"it will move to the right with a greater velocity than the original velocity of the big mass"* (CC1, Q1, S23, p13). He also gave a quantitative illustration of what he meant with an arithmetic example of specific values from his earlier calculations : *"before, 10 g 5ms⁻¹, after 10g 2.86ms⁻¹ and 2g 6.86ms⁻¹"* (CC1, Q1, S23, p13).

Nigel had one prediction correct in the pre test and two in the post test. His first pre test prediction suggested that the masses will stop immediately after the impact of the collision, making it also clear that he did not expect the collision to be non elastic (*"will not stick and move together"* (CC1, Q1, S24, p8)) or that the masses would change direction (*"will not bounce back"*). In the post test he predicted change of direction and velocity for the masses (*"will bounce back with the opposite velocity"* (CC1, Q1, S24, p8)). His third pre test prediction was correct suggesting that the masses *"will proceed in the same direction"*, making a distinction between elastic collision and inelastic collision *"at the same (lesser) velocity (inelastic collision) or they will proceed in the same direction, the smaller mass moving at a greater speed than the larger mass (elastic collision)"* (CC1, Q1, S24, p13). In the post test though, his prediction was incorrect, only predicting a

quantitative relation between velocities, but not mentioning the direction of motion post collision.

| Time | Student activity | Comment |
|-------|--|---|
| 00.00 | Familiarise briefly with the interface features by clicking on various buttons. | |
| 00.03 | Collision 1. watch the sequence (1,2), set random values of velocities on the gliders. | Establish positive and negative directions on the computer screen. |
| 00.05 | Change the velocities (choose random unequal values to set the masses moving towards each other) and watch the sequence (3). | |
| 00.11 | Collision 2 watch the sequence (4). | By using velocities pre and post collision calculate momentum before and after. |
| 00.17 | Watch sequence (5). | |
| 00.24 | Collision 3. Watch sequence. | |
| 00.31 | | Work individually with pen and paper. |
| 00.45 | | Write up their conclusions in the worksheet. |

Table 8.16. Observation schedule of students S23: Philip and S24: Nigel.

Philip and Nigel fared well in the first two tasks by successfully applying the conservation laws to the CC1 sequences. However, they failed to go beyond vague, qualitative statements in the third task. They alternated between linear/causal model and resistance/ reciprocal models in their explanations of collisions. They did not though use these in conjunction with conservation of energy and momentum to come up with relations between velocities and masses. (Transcript 8.7).

S24. So we have the big moving at [value of speed].
From Collision 2 we had a small mass hitting a big mass. And the small mass tended to bounce back.

S23. Yeah.

S24. If you have a high speed. It doesn't have to be negative... In the same direction... Basically you have a large object hitting a small object. The small object bounces back unless it's going very fast and with a large object hitting a small object, the large object will have to be a very slow one.

Transcript 8.7.

(CC1, T, S23- S24, p33)

They did not use much of the simulation, running each sequence a number of times (3 times for Collision 1, twice for Collision 2, once for collision 3).

In the third task they did a lot of calculations. They worked individually, discussing only briefly. Their final statements in the worksheet represented their solution to the third task. They came up with similar statements. Philip's was the more laconic one describing an instance of a collision while attempting to generalise about collisions: *"Small masses colliding into mobile large masses result in little mass moving back the opposite way and the big mass moving in the direction of which the small mass came."* (CC1, W, S23, p20)

Nigel was more explicit and tried to express a generalisation about all collisions which have the target-projectile typology. His response though was just a generalisation of his experience with CC1:

"Small mass hitting into immobile large mass will result in the large mass moving forward at a lesser velocity and the small mass bouncing back (unless small mass' velocity is very high). Large mass hitting the immobile small mass will result in the small mass moving at a velocity greater than the original speed as the large mass, in the same direction. The large mass will move in the same direction

at a smaller velocity than it originally had. If however the initial velocity of the large mass was very small it could bounce back. It is all a balance between the masses of the two objects. The greater the mass of moving object the slower it will have to travel to bounce back. The smaller the mass of the moving object the greater velocity it has to have to not bounce back.” (CC1, W, S24, p20)

Philip and Nigel did not use much of the simulation. Their collaboration was minimal since they preferred to work on their own with pen and paper rather than interacting together with CC1. They did not use the graphs which were also never mentioned as a form of representation of the simulation’s variables in their discussion. They did not go beyond the expression of qualitative statements, predicting the effect of different masses and velocities on the outcome of a collision: their overall predictor of post collision motion was, *“a balance between the masses of the two objects”* (CC1, W, S24, p20).

8.3.3. The CC2 simulation

In the end of the CC1 study, one pilot session took place. Two users interacted with CC2, a simulation of a 2-dimensional collision, where the vectorial nature of momentum has to be taken into account, resulting in high complexity.

The two users, Maria and Rick, were both competent computer users, they both had degrees in physics and they were chosen as it was thought that experts could test the simulation and deal with high complexity and the consequently “difficult” physics content of the

worksheet tasks. The aim was to explore the users' interaction when the physical reality of the simulation is complex and to investigate if this has implications on their exploration and understanding of fundamental physics laws, in this case conservation laws.

The users were first shown a figure depicting two colliding masses and they were asked to predict the outcome of the collision. The figure showed clear indications of the mass of the colliding objects and the modulus of the speed vectors:

If you have two masses moving as in Fig. 8.5, can you say what will be the outcome of the collision?

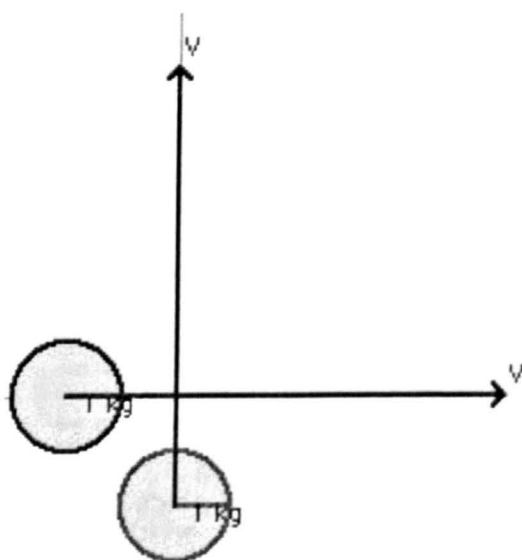


Fig. 8.5. The CC2 worksheet prediction.

Then they were asked to carry out two tasks using CC2:

- What initial speed must these two masses have in order to change their direction of motion (from moving on the x-axis to the y axis and vice versa) after the collision, and

- What is the minimum speed the masses must have in order to collide?

They experimented with varying the direction of the masses, constantly being surprised at how their predictions of the outcome of the collision were not the expected ones. In this aspect the simulation's simple visual representation helped them to visualise two dimensional motion and have some insights on the initial conditions needed to achieve collision. However they had difficulty relating these insights to the mathematical abstractions needed in investigating conservation laws, because of the increased complexity of the simulation (calculations in two dimensions). As Maria commented in the post test questionnaire: *"I could observe well the collision but I didn't get to notice the conservation of energy. Conservation of momentum was easier to see."* (CC2, Q2, S25, p26) and Rick *"It does not allow you to calculate very easily conservation of momentum and energy."* (CC2, Q2, S25, p26).

The two experts who interacted with CC2 had difficulty in carrying out the worksheet tasks and using the simulation effectively. It seems that the increased complexity level of CC2 made it unsuitable for novices. This was a deduction from experts' behaviour rather than from direct observations with novices.

8.3.4. Observational data

All participants were familiar with the Macintosh environment under which the simulation runs and they were able to manipulate the interface without any difficulty.

A common characteristic of all the interactions was that the graph facility was underused. The students concentrated on the digital counters to extract most of the information needed for their calculations. The ones who used the graphs had some difficulty in interpreting the graphical representation in the interface.

The use of physics metaphors such as vectors in the interface did not cause difficulties to the users, since they were already familiar to them from the physics formalisms in the classroom. The new element in the CC1 interface was the animated vectors of velocities which can act as enhanced physics metaphors.

8.4. Findings of the study

This section will examine the impact of the CC1 simulation on the users' conceptual learning. Also it will consider how the low fidelity, low complexity attributes of the simulation affected the learner's interaction.

CC1 was effective in promoting students' conceptual learning, as the quantitative and qualitative comparison between the pre and post interaction questionnaires indicated. The quantitative comparison

between the predictions showed a statistically significant difference between the total prediction scores. Another characteristic of the users' responses was the noticeable qualitative changes in their answers. This was particularly interesting to observe in students whose pre and post test predictions were both correct. In these instances, a qualitative improvement in the answers was quite common, in the sense that their answers were more accurate and scientifically complete.

A model, which was predominant in students who made incorrect predictions, was that of the colliding masses stopping immediately after the collision. The interaction with the simulation certainly helped to reshape this model by helping them to visualise instances of collisions.

The students fared relatively well in the first two tasks but, as in MM, in most cases they did not manage to complete the last task of the worksheet (relation between the relative masses and the speed of the small mass after the collision). They used both linear/causal and resistance/reciprocal models to explain and predict, but except in two (out of six pairs) they did not relate their explanations to the conservation laws, thus expressing the relations of masses and velocities by inadequate semi-qualitative statements ("slower", "faster").

A common characteristic of all the interactions was that the graph facility was underused. The students concentrated on the digital counters to extract most of the information needed for their calculations. In almost all the interaction protocols the graphs are not even mentioned, though they were discussed in the interviews where

the students commented on the graph facility and discussed their use of graphs (Chapter Nine).

Finally in the CC2 interaction, the two experts who interacted with the simulation had difficulty in carrying out the worksheet tasks. It appears that although the low fidelity interface was compatible with an expert's abstractions, the increased complexity of the simulation made the tasks open-ended and unsuitable for novices. CC2 was not further used.

8.5. Conclusion

In this chapter, after the outcomes of the study were presented, an attempt was made to link features of the interactions to certain characteristics of the simulation, and also investigate how these characteristics affect users' interactions.

CC1 (and CC2) had a visually simple interface (lower extreme of the fidelity scale), where the students could observe animated circles which represented colliding masses, and could also use graphs and digital counters to deduce the simulation's laws. CC1 was effective in promoting students' conceptual learning, as the quantitative comparison between the pre and post interaction questionnaires and the noticeable qualitative changes in their answers showed. The interaction with the simulation helped to change their views on colliding bodies by helping them to visualise instances of collisions.

A common characteristic of all the interactions was that the students concentrated on the digital counters to extract most of the information needed for their calculations and did not use the graphs.

In the following chapter a comparison of the two simulations MM (Chapter Seven), and CC1 is made in terms of their attributes which are relevant to the issues of this research. The chapter also examines the simulations in terms of usability from both studies. This usability study included a qualitative analysis of the users' opinions and preferences which were given in questionnaires and interviews in the end of each interaction.

Chapter Nine

Comparison of the studies and investigating usability in both simulations

9.1. Introduction

In the previous two chapters the users' interaction with the simulations was analysed. The data from each simulation were examined to determine which attributes of the simulation facilitated conceptual learning. Next a comparison will be attempted of the two simulations in terms of fidelity and complexity. The objective is to draw meaningful conclusions on simulation design from a comparison of the studies. But equally central to the design of software is the issue of usability, though the nature of educational software demands caution when usability criteria are applied. Research has recently attempted to establish specific conditions for the examination of educational software in usability terms. It is important to apply usability criteria to software without forgetting the implications for learning, as was argued in Chapter Six.

This chapter examines how users reacted to the design of the interface in both simulations. Students' reaction to the features of the simulation was important, and also their attitudes and perceptions (e.g. opinion about their performance, opinions on the effectiveness of the software and comparisons of the simulations). The aim was to find a general relationship between the students' descriptions and how these relate to the degree of realism they were offered earlier, i.e.

the characteristics of the simulation and their perception of the simulated environments. These together with the evidence from their performance would link the characteristics of a simulation and their effect on students' learning of the relevant physics concepts.

9.2. Comparison between the learning environments

Interaction with both simulations did improve the participants' ability to visualise outcomes of collisions and solve Newtonian problems. Both environments were effective in facilitating learning. Table 9.1 (also Fig 9.1) gives a comparison of the percentages of correct answers. The students, who were broadly similar in both groups, did better with MM than with CC as the pre and post test comparisons show (see 7.3.1. and 8.3.1. for investigation of the statistical significance of the studies). Since the complexity level for both was kept low, it can only indicate that the enhancement of the visual fidelity of an instructional simulation has positive effects on the learning outcome.

| | MM | | CC | |
|--------------|-----|------|-----|------|
| | Pre | Post | Pre | Post |
| Prediction 1 | 58% | 83% | 66% | 92% |
| Prediction 2 | 58% | 92% | 50% | 66% |
| Prediction 3 | 25% | 92% | 42% | 75% |

Table 9.1. MM and CC1, Post test: Percentage of correct answers.

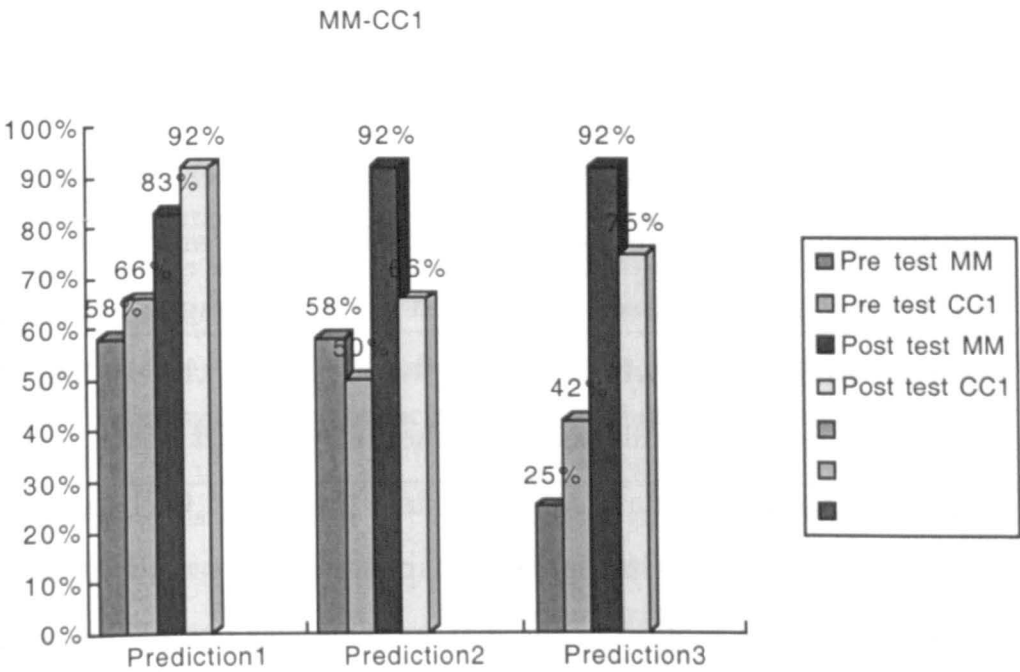


Fig 9.1. Comparison between percentages of correct answers in MM and CC1.

Another factor that supports the view that the simulation sequences and the collaborative work in front of the computer influenced students' ideas on collisions is the qualitative comparison between the pre and post test predictions. When repeating their predictions in the post test only a very small percentage of the participants repeated their pre test answers, the rest improved their predictions and gave answers which were more informed and better thought out.

MM represented a visually faithful (upper extreme of the fidelity scale) simulation. Its interface is a faithful representation of an experiment in the lab, with the use of video sequences as Quick Time movies. Furthermore in MM the Direct Manipulation abstractions of buttons and controls go beyond the interface level because the experience of the users (collecting data on the screen like they would

collect it in the lab) makes its behaviour more realistic and an experience similar to a real lab experiment.

CC1 (and CC2) had a visually simple interface (lower extreme of the fidelity scale), where the students could observe animated circles which represented masses, and could also use graphs and digital counters. Unlike MM, where the graphs were very closely linked to the data the students collected and where it was part of the learning procedure to see their data converted into graphs, in CC1 the graphs were part of the simulation display screen and followed synchronously the motion of the masses. This was one of the reasons that the participants of the MM study used the graphical representation more than the CC1 users.

In both MM and CC1, non-essential variables to the problems like friction and air resistance are omitted and motion is linear in one dimension. It seems that in MM, the realistic representation of video sequences convinced the users they were operating in a “real environment”. They tended to justify experimental errors using friction and kinetic energy loss, as the simulated masses visually move on air tracks, which in a real experiment reduce but do not eliminate friction. Students did not use similar statements in CC1 (and in CoC, Chapter Five), where they took for granted that the simulation was a frictionless environment.

| MM | CC1 |
|--|---|
| High fidelity/Low complexity (realistic, non ambiguous interface, easy to control). | Low fidelity/Low complexity (non realistic, ambiguous interface, easy to control). |
| Realistic representation causes uncertainty whether it represents a frictionless environment or not. | Use of representational physics formalisms leaves no doubt that it is a frictionless environment. |
| Video sequences are sometimes difficult to decipher, concerning details of interaction. | Details of visual representation clear to the users because of simple, schematic representation of the animated objects. |
| Use of video and real life context representation increases motivation. | “Decorative” elements, like backdrops and illusion of two dimensional motion are omitted so the users can concentrate on the physics formalisms of the interface. |
| | Animated vectors can act as enhanced physics metaphors. |
| The students interact with an environment which is similar to the real world. | Abstractions in the interface decrease the relevance of the simulation to real situations. Implications of decreased fidelity since what the students learn might be too dissimilar to the real world experience. |
| Users have no control over the values of variables. | Users have control over the values of variables. |

Table 9.2. Comparison of simulations: Multimedia Motion and CirclesColliding1.

The translation of interaction outcomes into meaningful comments was in many cases problematic because the students kept making repetitive quantitative comments on results of calculations and quoting repeatedly the physics formalisms when in perplexity about the solution to the task. This repetition sometimes acted as a refuge to the students when they had difficulties in proceeding in any of the tasks.

In the CC simulations, the exact point of collision was always clear to the users each time because of the “clear” representation of the animated objects (circles in CC), while in MM the students had sometimes to watch the video a few times to establish where the exact point of collision was. In a few instances, the videos of the observed phenomena were not very clear, even when observed frame by frame because of the small size of the MM screen on which the user operated, confusing the users when they were trying to extract information from a video fragment of the screen.

In CC's interface design, apparently inessential elements, realistic details like backdrops, and the illusion of two dimensional motion (which usually contribute to the user's feeling of operating in a real world) were omitted so the users could concentrate on the physics formalisms of the interface. The use of physics metaphors such as vectors did not cause difficulties to the users, since they were already familiar to them from the physics formalisms in the classroom. The new element was the animated vectors which can act as enhanced physics metaphors. In MM realistic details and allusions to elements of the real world made the context of the simulation relevant to the users.

There was also a difference in how MM and CC1 were designed to be used. In MM, a simulation of a laboratory experiment, the users were non-intervening observers rather than participants, in the sense that they could not control the velocities of the masses (though they had the opportunity to watch all the possible instances in different sequences). They could do nothing much to influence the outcome of

the experiment, which is usually argued to be a desirable characteristic of a computer simulation. This resulted in less user control than in CC1, where users were able to choose a big number of values of variables. In CC1 the users could manipulate variables (velocities) and observe the effects of their choices on the screen. They could cover a variety of possible scenarios which potentially could lead them to an understanding of the collision mechanisms.

The CC simulations use abstractions (colliding circles as metaphors of real objects) which decrease the relevance of the simulation to real situations, as the CC interface is an idealisation of a real physical phenomenon. Decreasing fidelity may increase ease of visualisation for novices but not necessarily conceptual learning and transfer of learning, since what the students learn might appear too dissimilar to the real world, for them to consider it applicable.

The next section describes a usability study which examined students' reaction to the features of the simulation and also their attitudes and perceptions of the interaction.

9.3. Usability study

9.3.1. Subjects and procedure

All the students who took part in the Multimedia Motion and CirclesColliding studies completed post test questionnaires and participated in one to one interviews. The main factors that guided the analysis of the interviews and answers in the questionnaires was

the frequency and fundamentality of the issues raised by the users (Adams et al, 1997). This analysis produced a number of factors which can be influential for simulation design. The emphasis was less on formal methods of usability and more on general human interaction issues.

9.3.2. Questionnaires

In the end of their interaction with the simulations, in the post test questionnaire, the students were asked to answer in writing the following questions:

What do you think of Multimedia Motion/CirclesColliding ? How satisfactory do you think the interface (what you see on the computer screen) is?

How satisfied are you with how you used the Multimedia Motion CD Rom/CirclesColliding simulations?

What do you feel you have learnt after using Multimedia Motion/CirclesColliding?

Do you think that working with Multimedia Motion/CirclesColliding helps to understand better conservation laws and collisions? (Yes/No)

If yes can you say how?

9.3.3. Interviews

The semi-structured interviews lasted approximately 10 to 15 minutes and were conducted with the participants of the studies, individually. They concerned the outcomes of their interaction and their perception of the simulations. The students were asked a series of semi-structured questions and were encouraged to describe the simulation that they used by covering issues of their perception of the simulation (interface, their performance, their opinion on the effectiveness of the software, comparisons of the simulations). This specific format of interview (semi-structured) was chosen because it allowed students to pick up on any areas then noted as being interesting or considered important, while they were working with the program and to introduce issues which they thought were not covered in the interview questions. Also it allowed the researcher to elicit further explanations on behaviours he noticed while observing the students. The questions, which formed the basis of the discussion with the students, were the following:

- Which explorations were most helpful in understanding conservation of momentum and kinetic energy? Why? (MM and CC1)
- Were there any explorations which were not helpful? Why? (MM and CC1)

As you worked through the explorations:

- Did observing the graphs after the video sequence help you to understand the phenomenon better? (MM)
- Did observing the graphs help you to understand the phenomenon better? (CC1)

- Could you easily see how each sequence of the video corresponded to a different point of the graph? (MM)
- Could you easily see how the motion of the circles corresponded to a the points on the graph? (CC1)
- How do you think the Multimedia Motion/CC1 explorations compare with “real” practical work?
- In your experience, is it easier to understand a physical phenomenon and the physics laws related to this phenomenon if the interface (what we see on the screen) is realistic like in a video or a photograph, or if it is very simple, e.g. line drawings of objects representing the real objects.
- Describe what changes you would make to improve the simulation?

9.3.4. User satisfaction

Perception of performance

The MM users' satisfaction with the way they performed ranged from positive feedback on their performance to dissatisfaction (Table 9.3).

| MM | |
|--|--------------------|
| Users satisfied with their performance | 7 out of 12 or 58% |
| Not satisfied | 5 out of 12 or 42% |

Table 9.3. MM: user satisfaction with performance.

Those users that showed dissatisfaction attributed it to characteristics of the simulation's design: obscure graphical representation which they felt needed to be further explained and lack of physical analogies

(vectors and counters) which would allow the user to penetrate the “reality” of the representation.

| CC1 | |
|--|---------------------|
| Users satisfied with their performance | 10 out of 12 or 66% |
| Not satisfied | 2 out of 12 or 33% |

Table 9.4. CC1: user satisfaction with their performance.

In CC1 the majority of the users considered the strategies they used during the interaction effective and felt satisfied with their performance (Table 9.4). The ones that expressed dissatisfaction felt they did not learn anything new from the simulation or they felt discontented because they did not reach a satisfactory result in the third task. In the following excerpt a student describes his experience with CC1: *“I got a bit aggravated when I couldn’t work out what the relationship was at the end but it was fun to use. It is easy to use, so I quite enjoyed it for that”* (CC1, IT, S16, p42).

Perception of software effectiveness

| MM | |
|---------------|--------------------|
| Effective | 9 out of 12 or 75% |
| Non-effective | 3 out of 12 or 25% |

Table 9.5. MM: percentage of users who find the MM software effective.

In MM, the students’ answers indicated that the majority (9 out of 12) believed they had learnt from the software and also that the simulation had contributed to their understanding of collisions. They felt that MM enhanced their learning of physics concepts (in this case momentum and kinetic energy), by giving them the opportunity to apply these concepts to “real life situations” (MM,Q1, S10, p4). The use

of the simulation meant to them the transition from theory to *"practice"* and *"real life"*.

The high fidelity interface of the simulation, where the students applied Newtonian laws to realistically behaving objects, gave them the feeling of applying the physics laws and concepts to the real world. As one student commented, *"It made me see how what I have learned in lessons can be used outside of lessons"* (MM,Q2, S6, p21).

For some of the students the novelty in relation to the previous experience in physics was that they had first to negotiate with each other and then analyse and explain the results of their choices (e.g. choice of points for collecting data on the computer screen). They compared this experience with the experience of solving a physics problem based on abstract mathematical calculations. As one student commented: *"there was a lack of numerical calculations"* (MM,Q2, S11, p20), meaning that there was an emphasis on qualitative reasoning in their interaction.

The students referred to the ability of the MM user to observe repeatedly a sequence and study it in detail, to examine the graphs of position, velocity and acceleration against time before negotiating some explanation and the ease of collecting data with MM compared to a similar experience in the physics lab (e.g. time saving). Additionally they thought that the set-up which can be run and inspected at all times is better than practical work because, *"It is very close to the real thing if not the same"* (MM, Q2, S4, p20), while some others disagreed about the credibility of the simulation. They thought that the collected data was not translated into easy to understand

graphs. Two of them attributed to the simulation a lack of accuracy which was related to the “poor” translation of the data in graphical representation: *“it’s not very accurate and some of the set-up is frustrating.”* (MM, Q2, S3, p19).

Another type of comment referred to the software itself and not the content of the simulation. So students commented after playing with the simulations that *“a problem can be made easier by using computers rather than making the experiments ourselves”* (MM, Q2, S12, p22), and that *“CD ROMs are a good way to learn”* (MM, Q2, S5, p20).

They had also interesting intuitions about the difficulty of visualising in physics and which attributes of the simulation contribute to motivation, e.g. *“animation makes visualising the model more interesting.”* (MM, Q2, S3, p21). As one student commented, *“you don’t have to visualise the collision yourself, you have real-life data to play with and you don’t have to plot your own graphs.”* (MM, Q2, S1, p21).

| CC1 | |
|---------------|----------------------|
| Effective | 12 out of 12 or 100% |
| Non-effective | 0 out of 12 |

Table 9.6. CC1: percentage of users who found the software effective.

Table 9.6 shows the percentage of CC1 users who found the software effective in helping them to understand conservation laws and collisions. All CC1 users commented positively on the interface. They thought that using a simplified visual model of the phenomenon could be useful because it facilitates the solving of a problem. They

provided a range of descriptions of the interface commenting on its simplicity (*"kept very simple and very easy to understand,"* (CC1, Q2, S13, p21), or *"the interface is good as it is simple, so it is obvious what is happening"* (CC1, Q2, S18, p21) and *"it was clear and the graphs were easy to read"* (CC1, Q2, S20, p22)). They also commented on the way it showed the collected data in the hybrid screen in multiple representations (*"showed us all the necessary figures e.g. speed before/after"* (CC1, Q2, S14, p21)), and on its informative nature (*"it is easy to see all the information at once"* (CC1, Q2, S15, p21)).

The CC1 users felt that the simulation helped them to visualise instances of collisions, also enhancing transfer of learning to similar situations by making the interaction with the simulation a memorable experience, as illustrated in the following quotes: *"...you get to see graphically why momentum and kinetic energy is conserved etc... how the energy between them is transferred and you can just visualise it. It's easier to understand/remember because of that."* (CC1, IT, S16, p43)

One of the participants summarised correctly that the use of the simulations made clear for him that colliding masses do not always stop after the collision, which was one of the common preconceptions the users of the studies had. As he commented, the simulation helped him to realise that *"two equally massive bodies when moving towards each other with separate velocities can bounce back in the opposite directions at the same velocity to conserve momentum rather than becoming immobile"* (CC1, Q2, S24, p24).

9.3.4. Qualitative analysis: results

The analysis of the interviews and questionnaires produced a number of factors which either were considered fundamental by the users in their learning experience with simulations or were mentioned frequently in their affective comments. These issues were: comparison with alternative learning experiences, the realism versus abstraction “conflict”, the interface and graphs.

Comparison with alternative learning experiences

The experience in the classroom was the point of reference to which the simulations compared as substitutes or as complements of traditional learning experiences. The users compared their experience with the simulations to similar experiences in the physics lab. The similarity was more intense in the case of the MM sequences, since while using the MM sequences, the user also simulates data collection (by clicking on appropriate points on objects on the computer screen), similar as to the end results to data collection in the lab.

The majority of the users commented favourably on simulations in comparison to alternative learning experiences such as learning through teaching in the classroom, reading a textbook, or doing experiments in the lab. As someone commented on a simulation’s teaching value: *“if I had been taught in this way from the start, it probably would be better than just reading from a book”* (CC1, IT, S20, p46).

When asked if the experience with a simulation is comparable to “real” practical work, the students mentioned such comparative factors as the complexity and unpredictability of the experiments in the laboratory, which can result in experimental error. In the case of MM, where the simulation data are instantly recorded and plotted on a graph, the experimental error factor in the results is reduced. As one student commented: *“it is good for learning a concept and seeing it work without experimental error”* (MM, Q2, S9, p22).

Their objections in accepting the simulations as an experience equivalent to practical work related to the limits in representation, and inherent drawbacks of computers in relation to a 3-dimensional objective reality: *“computers cannot be used for all of the lessons because they are 2-d”* (MM, Q2, S18, p25), meaning that representations were two dimensional in contrast to the three dimensional real world. According to the students, the underlying physics model is not always a faithful representation of reality because, as a student commented, *“you only get the information which the programmer has put in”* (CC1, Q2, S20, p22). They also referred to the difficulties of human computer interaction in relation to negotiating physics explanations in the classroom: *“it’s not as easy to ask a computer questions”* (MM, Q2, S2, p19).

Another point of reference was also the real world. For many of the users nothing compares to the memorability of the real experience. As someone commented: *“If the lab was properly organised you could explain it in an easier way, because you would be doing it yourself... If there is a proper equipment in the lab it would probably be better because you would relate to it.”* (MM, IT, S1, p39).

In the following excerpt, another user describes how even realistic video or virtual reality cannot be compared to the real experience (Transcript 9.1).

- S8.** If you could run a full screen movie and actually plot on the movie. But the movie is so small you can't actually relate to it.
- Researcher.** If you make it bigger you lose the quality of the picture. Do you think is easier to understand the phenomenon if you see a realistic video?
- S8.** I guess so. But even watching virtual reality is still not the same as watching the real thing. Like when the space shuttle blasts off, you get so far through it then the smoke shields it off. Also because of the fixed point camera it actually goes off the screen, so you don't see all of what you are looking at.

Transcript 9.1.

(MM, T, S8, p42)

Realism versus abstraction

The users attitudes towards the degree of realism they were offered, indicated a preference towards schematic representations of reality. A small number of them showed a preference for the realistic interface of MM. They claimed that it is easier to understand a physical phenomenon and the physics laws related to this phenomenon if the interface is a high fidelity one rather than a schematic representation like a drawing. As someone suggested, high fidelity interfaces might be more motivational: *"it would be more interesting for people who don't enjoy physics as much, if you wanted to interest them more"* (CC1, IT, S16, p43).

They also thought that high fidelity contributes to a better understanding of the physics laws because the user can observe meaningful data from a realistic interface. As one student commented, *"with a video it is easier to relate the facts or laws to the object because you can actually see the object moving as it would be in real life"* (MM, Q2, S5, p20). Another added, *"with a video you could freeze frame and it is more complex (than a) simple drawing which is also easy to use, although sometimes it may be too simplistic (CC1, IT, S13, p40).*

But there was a contradiction in their responses to the high fidelity interface: their first impulse was to answer that *"it is easier to have a video than a drawing"*, meaning a schematic animation, but they considered it more difficult to penetrate the reality of a high fidelity simulation and they felt that to understand the concepts and the interrelation of the variables a simpler low fidelity representation would be more helpful. A characteristic comment of this type which indicated their preference for a simple semi-transparent interface, in relation to the underlying physics model, was, *"you see lifelike pictures so that you can actually see what happens but it would be easier to understand the concepts behind it if it were a simpler representation of the experiment"* (MM, Q2, S11, p22).

Three users showed a preference for a potential combination of high fidelity interfaces which provide a real world-like feeling and low fidelity schematic ones which present a representation of the underlying physics model without unnecessary attributes. As a student commented she could not indicate a preference for high or low fidelity interfaces because *"they were both useful"* as the former

“give realistic events” while the latter “are easier to see and understand.”

For others (10 out of 16), their preference was clearly towards the schematic representation of CC1. The following excerpt shows this attitude and follows a student’s attempt to compare abstractions in physics and a real world experience (Transcript 9.2).

- S18.** The spheres are simpler. You can actually see the differences.
- R.** So you think it’s easier to work with something abstract.
- S18.** Yeah.
- R.** But when you see something in the street in real life, can you relate it to the circles you used in the simulation?
- S18.** Yeah, I think you can actually visualise and compare it to what happened to the circles and why it happened.
- R.** You mean you can apply this to similar situations in the real world?
- S18.** It’s like if you had two trains that went splat, you know what happened if you have seen the simulation.

Transcript 9.2.

(CC1, IT, S18, p45/46)

The users preferred CC1 as they were apprehensive that the realistic representation would increase the level of difficulty of the interaction. In MM the animated objects might be too complicated, because of shape, size and the overall non clarity of the interface, as illustrated in the following transcript (Transcript 9.3),

R. Would you prefer to use a simulation like that? How would you find it in terms of difficulty?

S14. It might be more difficult.

R. Why is that?

S14. Because with spheres you can concentrate just on that but when you have two different things like a car and a motorbike it's more difficult because you might get confused because it's a different shape. You have lots of things around it so you get distracted from what's really going on. The plain thing of two circles and an arrow is much easier.

Transcript 9.3.

(CC1, IT, S14, p41)

and (Transcript 9.4).

S22. If you use the MM one and you must get calculations of whatever you can think, e.g. a car has four wheels, a motor-bike has just two, a motor bike can go faster.

R. You mean there are a lot of factors which were not included in the first one.

S22. Yes, if you just use these circles they are identical apart from their masses and velocities. So there are no reasons you can come up with why you get these values, why you get these answers. Other than the different masses and velocities.

Transcript 9.4.

(CC1, IT, S22, p48)

Another attitude expressed by a minority of the users was that it would be equally easy to use any of the simulations, as the underlying physical model was the same. As someone commented: *"It would just be as easy to use that as it would be to use the other one. The difference being you see two balls colliding instead of two computer drawn objects colliding. So there really isn't much difference. The only difference is a whole lot of memory."* (CC1, IT, S13, p40). This

was also a significant comment on the users' perception of the underlying model (see also Chapter Three) which can be simplistic and not take into account individual characteristics of each model.

Interface

The interviewees were shown a screen dump of the simulation they had not used earlier (screen dump of MM for the CC1 users and screen dump of CC1 for the MM users) and were encouraged to make comments on both interfaces. Most of them showed their appreciation for an intuitive, easy to understand interface which would reveal ideally as much as possible of the physical reality. A characteristic comment of this type, referring to the interface as an entity between the simulation's laws and the user, was: *"The simulation is easy to control and the interface does not get in the way."* (CC1, Q2, S15, p22).

Two important criteria for the users' acceptance of the interface as satisfactory were ease of use and simplicity of design. The simplicity of the interface in the case CC1 was complemented by giving user control over the simulation environment. An example of a comment of this type was, *"The simulations were easy to use and allowed the user to find helpful information on the masses at any stage of the collision. This is aided by a simple but effective interface."* (CC1, Q2, S16, p21).

Also the students referred to the interface as an interpreter of the real world. As someone commented, the interface can make things simple

for the learner, by providing all the necessary information in a simple form: *"The program helped with real life simulations and made the problem easier to understand because it showed us all the necessary figures e.g. speed before/after. This program helped us to look at the problem in a reasonably simple way which was made easier to understand."* (CC1, Q2, S14, p21).

This role of the interface as a negotiating medium between reality and the physics of the simulation was not appreciated by others who preferred MM as it was *"easier to understand the phenomenon if you see realistically looking objects."* (MM, IT, S1, p39).

A possible drawback of the CC interface was that there was no facility for saving the collected data, since only the currently used data were shown on the screen (whereas in MM the collected data were presented in a spreadsheet). As a consequence it was not possible to compare the data which should facilitate the deduction of relationships between the variables to find generalities. As someone commented: *"the simulation is laid out clearly so that it is easy to see all the information at once. However it is not so easy to see general relationships because only the current data is visible on the screen"* (CC1, Q2, S15, p21).

Graphs

The students' attitude towards the graphs was ambivalent and depended on which simulation they were using. In general there was a reluctance to use the graphs.

The majority of MM users thought that the graphs (especially the acceleration ones) were difficult to understand, but they considered the displacement and velocity graphs slightly easier to extract information from. They attributed any fluctuations on the graphs either to a not very thorough data collection (experimental error) or to friction. The following transcript describes common attitudes towards the MM graphs (Transcript 9.5).

- S8. The graphs didn't show any pattern, they were so scattered. The line of the best fit didn't make sense. So when you put it into the formulae you get the calculations out, the accuracy is just not there.
- R. Did you find in this kind of graph you could correspond each part of the graph with a special sequence of the movie/simulation.
- S8. Yes.
- R. So you think you needed the graphs but these graphs weren't good enough.
- S8. Yes, they were too sensitive. You couldn't look at the graphs and understand what they were trying to represent.
- R. Which of the graphs were more helpful?
- S8. The acceleration and the velocity on x but the y graphs were usually so scattered it didn't make sense.

Transcript 9.5.

(MM, IT, S8, p42)

Another type of comment were that the points were scattered and they could not easily correspond to a best fit straight line. As someone commented: *"the acceleration graphs were not helpful because once we had created the data the graphs did not plot properly"* (MM, Q2, S4, p21) or *"with displacement and velocity it was clear yes but with acceleration this was hard to see (because of the way it changed so*

erratically on the graph)" (MM, Q2, S6, p22). Someone else suggested that it would be easier to interpret graphs, if the graphical facility should also calculate gradients of the best fit lines: "I think it would be good if you could have some way of totalling things up or finding gradients." (MM, IT, S5, p40).

In CC1 the graphs were synchronous with the motion of the animated objects in the simulation interface. The user could compare how each sequence of the simulation corresponded to a different point of the graph. As someone commented (Transcript 9.6).

R. Do you think it is easy to watch at the same time the spheres moving and the changes in the graphs.

S16. Yeah reasonably easy. It's all simultaneous, you can see when they collide, the graph on, so it was reasonably easy to compare the two, everything was easy to see because it's uncluttered. So you could compare the two. It wasn't like you had to watch one and then the other. This would have been more difficult. You could see it all at once.

Transcript 9.6.

(CC1,IT, S16, p44)

However, the students did not use the CC1 graphs extensively. The reason they gave for that was that the digital counters were more "user friendly". It was considered easier to read the values of the variables on the digital counters and ignore the graphs. Transcript 9.7 illustrates this point.

R. So you prefer working with the counters?

S14. Yes, It was good being able to run it back and forth through it, because you could see how it changed when it collided. On the graph you couldn't really see that.

Transcript 9.7.

(CC1, IT, S14, p42)

For some users the CC1 graphs were also difficult to read because the scale was not sufficiently big (Transcript 9.8).

S14. They were a bit small. I wasn't sure what all these bits were.

R. Did you use them a lot?

S14. No, not really. If maybe they were bigger or made more clear. Because it was small, it was difficult to see where everything was on the scale. So it was much easier to look at the table down at the bottom.

Transcript 9.8.

(CC1,IT, S14, p42)

Another comment indicated a more "sophisticated" rationale for preferring counters than graphs (a velocity graph is useful only when the velocity is not constant, referring to the constant velocity of the masses before and after the collision), Transcript 9.9).

R. What about the graphs? Did they help, did you use them a lot?

S16. No, not really. I think we used the numbers pretty much... Well, I mean that the graphs would have been much more helpful if there was acceleration, As it was steady, so acceleration wasn't so important in the simulation and there was no point in the graph. It is just as easy to read off from the numbers what a straight line is.

Transcript 9.9.

(CC1, IT, S16, p43)

9.4. Conclusion

The production of successful interactive learning environments is intrinsically connected with the use of carefully designed software which is also thoroughly evaluated. A summative evaluation was carried out of the two simulations by using quantitative and qualitative analysis of the collected data.

Both MM and CC were effective in facilitating learning: the interaction with the simulations improved the participants' ability to visualise outcomes of collisions and solve Newtonian problems. The students, who were broadly similar in both groups, did better with MM than with CC.

Users' comments and opinions are also important for evaluating educational usability. The subjective comments of the users in these studies were helpful in indicating preferences and opinions, expressed either in questionnaires, protocols of the interaction or post test interviews.

Users of these studies had clear opinions on the kind of interfaces they would ideally like to use. Their attitudes towards the degree of realism they were offered showed a preference towards interfaces with a schematic representation of reality. They showed a preference for the CC1 simulations, where the colliding objects are represented by idealisations, rather than the high fidelity environment of MM. The MM interface was a novelty and probably alienated the users who were used to schematic representations of reality from physics problem solving in the classroom.

The users explained their preference for low fidelity environments by assessing their interfaces as visually simpler. They considered it to be more difficult to penetrate the reality of a high fidelity simulation. A minority also indicated a preference for a potential combination of high fidelity interfaces which provide a real world-like feeling and low fidelity, schematic ones which present a representation of the underlying physics model without unnecessary attributes.

The students' attitude towards data representation in the simulations' interface and towards the graphs was ambivalent and depended on the environment they were using. In general there was a reluctance to use the graphs for extracting information and their preference was towards numerical information given in the digital counters.

Finally a number of factors were repeatedly mentioned in the user comments and explanations on the representation of physical reality in simulations. These were the interface, the use of graphs and the debate as to whether educational software can substitute or enhance the educational experience in the laboratory and the classroom.

The next chapter discusses the findings of the studies in relation to the hypotheses in Chapter Six. The implications of the findings for simulation design are developed as an interface syntax, a set of guidelines which should be taken into account when designing computer-based learning environments.

Chapter Ten

Conclusions

10.1. Introduction

In this final chapter the original research questions are considered in the light of the findings. The overall claim of the thesis is that it has contributed to a better understanding of the factors which promote successful use of educational software. The thesis supports the view that well designed computer-based learning environments can promote learning. The findings of the case studies suggest that design issues identified as worthy of exploration in this thesis are essential to the creation of successful simulations. These ideas are examined in detail in this chapter. The outcomes of the studies are presented and implications for simulation design are also examined, followed by a discussion of design criteria for how systems might be built. The discussion of the outcomes is followed by a critique of their applicability, a consideration of their limitations and finally the scope for further research.

10.2. Findings from the studies

In this section the findings of the studies are presented and compared with the research hypotheses from Chapter Six.

10.2.1. Enhanced fidelity level

The studies investigated the effects of variations in fidelity on learners' conceptual learning. The findings suggest that the enhancement of the fidelity of an instructional simulation has positive effects on the learner outcome. In high fidelity simulations, the user performs activities which are not facilitated by the use of simplistic, visual idealisations but the relevance of the simulation to real situations is increased. An appropriate combination for novice learners would be that of high fidelity with low complexity, when there are many variables to consider in the underlying model. High fidelity and low complexity simulations put an emphasis on making the learning activity relevant to the user experience and can familiarise learners with the abstractions of physics, by combining simple Newtonian physics formalisms with a visual representation to which they can relate to from their everyday experiences (Chapter Seven).

It seems that most users tend to show a preference for low fidelity interfaces (Chapter Nine), considering them simpler for extracting information. Low fidelity simulations lead to more positive perceptions of ease of use than high fidelity ones. Also designers and educators may sometimes regard, as an obvious design choice, the use of pure physics formalisms and idealisations in interfaces for representing physics knowledge (Chapter Four). Research (Sedighian & Westrom, 1997) though has indicated that interfaces with the lowest cognitive effort are not the most educationally effective. Another consideration is the trade-off between "parts that are not necessary for students to learn and should be made easy, and parts which are

absolutely critical, where the students should be allowed to struggle to gain mastery of the material" (Rappin *et al*, 1997). Interface design obeys complex considerations which should include: users' preferences and perceptions of ease of use, how representations can facilitate connections to the real world and make physics relevant, use of memorable interfaces and the sense of the user being in control of the learning environment.

It seems that there is a balance between design and use of interactive learning environments that should be kept if all the above considerations are obeyed: a combination of interfaces in which the emphasis is on richness of external representations ("qualitative interfaces") and tasks that encourage "quantitative" actions from the users (use of mathematical descriptors and quantitative reasoning), Chapter Five and Chapter Eight). However, this "qualitative" high fidelity aspect of the interface has to be enhanced by indications of the physical reality, by the use of multiple representations of the simulation's underlying model.

10.2.2. Multiple representations

Simulations which focus exclusively on the external representation and downplay the indications of the physical reality (numerical output, measures, etc.) disturb the ideal balance that should exist between visual, numerical and graphical representation. They encourage the use of spontaneous, qualitative and semi-qualitative comments to describe the physical reality, forgetting the mathematical principles which describe this reality. The use of multiple

representations with clear indications of the physical reality, either through digital or graphical representations, reinstate this balance.

Interfaces where the user has the option of converting the physics reality into different forms offer valuable information which facilitates problem solving strategies. The two most common forms of multiple representations in simulations are numerical counters of the simulation variables at any time and graphical output of the variables over time. The difficult trade-off in this case is between essential information and an overload of counters, graphs, and other indications of the physical reality. An option may be for the information to be presented in a "choose and pick" form for the user. Of course the context in which the simulation is used is important for making decisions about the order of presentation. In the domain area which was chosen for this research, a first consideration was to give the users the ability to view several instances of collisions before proceeding to use the information provided by graphs and counters to investigate principles and carry out tasks.

An implication of the use of multiple representations concerns also whether there is an appropriate sequencing of this information so that the users' actions will be guided, for instance, they will not be able to do something before accomplishing something else. In MM (Chapter Seven) the user must collect a minimum number of data before converting it into spreadsheets and graphs, while in CoC (Chapter Five) and CC (Chapter Eight), the user inspects while interacting with the simulation synchronous counters and graphs throughout the run of each simulation sequence.

Digital counters keep track of the values of the simulation variables and sometimes present combinations of the variables (e.g. in Puckland, Chapter Two, the user is presented not only with the values of velocities but those of momenta and kinetic energies). There is an indication that graphs are more powerful than any digital counter. This research indicated that students had difficulties in reading graphs and making effective use of them. It has also shown that users tend to deliberately ignore the graphical information, if graphs are combined with any other kind of equivalent representation (e.g. digital counters), discarding it as difficult to understand (Chapter Nine).

Graphs which are presented in a raw form (e.g. points without the best fit line, in the case of straight line graphs, as in MM, Chapter Seven) may seem daunting to users, since they are sometimes presented as scattered points which the users must connect in order to read the graph. A simpler presentation would emphasise clear graphs, of adequate size.

Interface design should help students towards quantitative reasoning, away from vague reasoning based on causal/reciprocal intuitions, and should incorporate the “maths” in the task completion framework.

10.2.3.Complexity level of simulations

The studies suggest that low complexity simulations are better suited to the exploration of laws and principles by novice learners, though the investigation of the range of values of complexity which was carried out was not sufficient to state this with confidence.

The simple underlying model in low complexity simulations can be explored easily by novices, since the number of controlled variables is small and the equations which describe the relationship of the variables and the behaviour of the simulation objects are simple (Chapters, Five-CoC, Seven-MM, Eight-CC1). As complexity increases it becomes more difficult for novices to explore the model and complete the learning tasks (Chapter Eight-CC2). Increasing the complexity has implications for students' learning, since the number of variables involved is not as easy to control and the equations between the variables become more complicated.

Once the students have mastered the simple cases, they can build on the knowledge acquired from low complexity simulations, by moving on to explore more complex underlying models.

An example in mechanics is the use of linear collisions to teach the laws of conservation to novices, as demonstrated in the simulations used for this research. For the students, learning principles and laws of conservation should not necessarily be a consequence of dealing with composite motions in two or three dimensional space, which sometimes obscures the fundamental physical principles. After acquiring knowledge of the mechanics of a linear collision environment, learners can proceed to understand the dynamics of collisions in two or three dimensions.

One important implication of the use of simulations whose underlying model is more or less a black box is that users do not have a clear sense of the simulation's underlying model, or take any part in creating or changing the model that drives the simulation. This may

result in the users having simplistic views on the underlying model as a system, which *“just applies physical laws”* (MM-pilot, Q2, P9, p20), Chapter Three.

10.3. Design criteria: a syntax for physics simulations

In this section some design criteria based on the outcomes of this research are presented. These criteria do not claim to be universal in their applicability. The claim is that the design of computer simulations would benefit from the use of an appropriate interface syntax.

10.3.1. High fidelity representations

Representations of high fidelity challenge the physical knowledge of the users, presenting them with a reality visually richer than the idealisations in physics problem solving. An appropriate combination would be with a low complexity approach towards the underlying model. Representations of this kind provide a simplified reality which, despite the underlying model idealisations, do not alienate the users because they are visually relevant to their real life experiences.

The use of video can enrich the learning experience. Vossen et al (1997) point out that video is good for presenting something that moves physically rather than a more static object, and, as a highly dynamic medium, it is also good for raising the users' attention. The use of video increases motivation, as research on the use of video in the interface also indicates (Christel, 1994). This is true for such

simulations as Multimedia Motion, which was designed to enhance motivation.

10.3.2. Fidelity sequences

Combinations of simulations of different fidelity were suggested by the users as a link between external representations and physics formalisms. A step up towards high fidelity or step down towards lower fidelity would link the world of vectors and abstract shapes to photographic representations of objects which behave similarly to their abstract equivalents. The order can be decided by the designer or the teacher. Possibly the order is not of major significance as long as the user is presented with both aspects of the physical phenomenon: animated abstractions to which she is familiar from the formalisms used in the physics classroom and objects in the context of real situations of a relative visual sophistication.

10.3.3. Real time

Real time (high time fidelity) is valuable unless the changes which must be observed take place over a long period of time. High time fidelity enhances the user's feelings that she operates in an environment which not only looks but responds like the real world. In cases where the use of low time fidelity is thought to be necessary, a function which would allow the user to experiment, by varying the step, will contribute to her appreciation of the appropriate use of the variable time in the study of natural phenomena.

10.3.4. Interface syntax

A careful consideration of the syntax of the interface should extend beyond the design decision about which multiple representations are necessary for providing the students with the essential tools for exploratory learning. The order by which they will be presented or explored by the user should also be considered. A characteristic example is the use of the graphs of the Multimedia Motion (MM) simulations by the students in relation to their use of graphs in CC1 and CoC. In the former the structure of the simulation created a sequence of actions (plot points, examine spreadsheets and graphs) which determined the sequence by which the students would examine data representations. Also the absence of digital counters in MM made the users visit the graphs and spreadsheets to extract information about the values of the variables. In the latter the graphs were a constant feature of the interface which the users had the opportunity to see all the time, in combination with the digital counters. As a consequence their preference was for using the counters almost exclusively. In most cases they ignored the graphs or they acknowledged them passingly as attributes of the interface.

Graphs

Graphical representations are especially useful in physics where data have more than one numerical dimension (parameter values changing over time). Careful design of the display of the graphs (of adequate size, and careful shading to make them legible) is essential. There are two main categories of graphical representation: charts (line charts, as in CC and scatter charts, as in MM), and simulated gauges (in

the CC simulations, the user could transform the digital counters into simulated gauges). Line charts are probably the most important for delivering the relationship between variables in physics to the user of the simulation: they show how the variables are interconnected. Time should normally be shown on the horizontal axis, as this is usually the standard convention for this domain.

Fields vs gliders

Fields, where the user can input exact values of variables are more accurate than gliders (or radio buttons). A problem found with some simulations is that the user is presented with rough divisions of the values of the variables (see Chapter Five, in ColaCollision where the mass were Small, Medium and Big, CC1 and CC2 where the masses corresponded to specific values not changeable by the students). In the case of the CC simulations and ColaCollision this was a design decision for reasons of simplicity, but in general the design should provide the user with as much control as possible by allowing her to make decisions and choose the values of variables, especially in open ended problems which need substantial tools of experimentation to facilitate the use of scientific reasoning.

Size of the screen

The impact of educational software is enhanced by the use of adequate size screens. The size of the screen must be adequate, as details which are valuable for getting a sense of the physical phenomenon should be clear.

The size of the video screen in MM was criticised by the students as inadequate. They claimed that details which were valuable for understanding were blurred and not clear to see because of the size of the video extract. It is also true that most video excerpts on computer screens are of relatively small size because of memory limitations, and that they give poor images when they can be blown up. This can result in difficulties and misunderstandings (for instance confusion as to where is the exact point of impact between colliding masses).

Revisiting the simulation

It should be made possible for the user to go through the simulation frame by frame (as in both MM and CC simulations). By doing this she can watch in detail instances of the phenomenon which otherwise would not be clear enough and also observe closely the correspondence between graphical information and instances of the animated phenomenon. The problem of revisiting the simulation in some simulations was solved by the addition of a recording facility (ColaCollision - Chapter Five, DM³ - Chapter Two), using which the user could replay the sequence (for every choice of variables) as many times as she wished. The necessary functions of such a facility should be Play, Pause and Replay.

Database

A database facility keeps track of the values of the variables. When the users are asked to extract regularities from a reasonably big number of different combinations of variables, a data saving facility can provide a database of information which can be examined by the users in their

attempt to find patterns and extract laws from raw data. This was a characteristic of MM (Chapter Seven) where the collected data could be saved and presented in the spreadsheet. A data logging facility was a characteristic which the users of these studies (Chapter Eight) thought to be very useful.

10.4. Contributions and achievements

The aim of this thesis was to explore the design of interactive computer simulations. The particular learning domain selected was Newtonian Mechanics. Mechanics was chosen as it is an important area of physics in which many students have difficulty in visualising aspects of the phenomenon under study and predicting outcomes of phenomena. A second reason for the choice of mechanics as an appropriate area was that motion can be represented effectively on the computer screen with animation or emulated video, thus taking advantage of the computer's graphics and interactive capabilities.

The software used simulated the collision of masses on a display screen. The purpose of the simulations was to focus the students' attention on aspects of collisions (masses bouncing off other masses according to size and speed) and how the outcomes of these collisions are closely related to Newtonian conservation laws.

Implications arise about the students' willingness to move between their real world experiences and ideal learning environments in order to justify and explain their findings. This is related to the flexibility of attributing to computer based simulations a wide range of reality representation values, from being totally realistic to being idealised.

The interface's visual representation showed the users graphical environments which resembled the real world to a greater or lesser extent. The two extremes these representations ranged between were animated phenomena, like in a video, and abstract idealisations of masses, presented as circles moving on the computer screen. On the other hand the underlying physical model determined the behaviour of masses, in terms of how complex the physical equations which comprised the model were.

An analysis was made using three different perspectives:

- from the point of view of physics problem solving, with an emphasis on the strategies the students used to complete tasks in an instructional cycle. This interaction in a collaborative setting facilitated "dialogue" between the physics as a disciplinary approach and the common prior conceptions the students held.
- from the point of view of strategies (if any) which the students used while using the simulation software and what these strategies revealed about useful or significant meanings for the nature of the software.
- from the point of view of the users' perception of the simulations, perception of their performance and other usability issues. Another consideration was how the attributes of the simulations were linked to these opinions and attitudes.

This thesis contributed:

(i) a detailed literature review on CAL (computer assisted learning) in Science, focusing on the use of computer simulations in physics. An effort was made to put computer simulations in the context of CAL as

a whole, and to discuss their use in physics, which is a subject with unique characteristics in the whole of science. The view promoted in this research is that the effectiveness of simulation software is dependent on its appropriate use within an instructional cycle, similar to the ones described by White (1992), Tao et al (1993) and Lunetta & Holfstein (1991). However, there are still objective design criteria which make interface design influential and facilitate its use for learners. This is in contrast to research (Roschelle, 1994) which suggests that designers should focus on supporting communicative practices instead of representing mental models. The view of this research is that collaborative practices should co-exist with but not replace consistent, well designed interfaces.

(ii) a broad analysis of the factors that constitute a successful simulation (interface, motivation, underlying model and representation of reality), with an emphasis on the interface and the underlying physical model as significant factors for communicating the disciplinary approach to learners. As a consequence of this approach two small case studies took place with users interacting with two simulations, which investigated interface and underlying model issues.

(iii) a research methodology which is appropriate in studying interaction with computer simulations, and an explanation of why the use of computer supported collaborative learning methods is more appropriate for eliciting explanations from the students than a face to face session with the teacher or the user working individually in front of a computer.

(iv) a presentation of a number of studies of students using computer simulations and an analysis of the interactions and what they reveal about the way students use and perceive simulations. The results reveal that the students had beliefs derived from living in the real world (individual frameworks, see 2.2), which sometimes interfered with their ability to understand collisions.

(v) an evaluation of the use of simulations by the students which involved cognitive and affective factors. An explanation of why such an approach is appropriate for studies of this type was also given. The view of this research was that users can only provide valid feedback and talk about usability issues after they have interacted with the simulations in an instructional mode, completing tasks.

(vi) A set of guidelines for the design of computer simulations, and within the constraints of research of this type an interface design syntax. These guidelines could possibly be applied to other domains, but with caution, as the students' simulation experience in physics may bear little resemblance to simulations in other domains, because of the specific physics formalisms.

Table 10.1 summarises the contributions of this thesis.

| CONTRIBUTIONS |
|---|
| Literature on computer simulations in the context of computer assisted learning. |
| Simulation taxonomy: factors that contribute towards a successful simulation (interface, motivation, underlying model and representation of reality). |
| Overview of the research methodology which is appropriate for studying interaction with computer simulations. |
| Analysis of a number of studies of students using computer simulations. What they reveal about the way students use and perceive simulations. |
| Evaluation of the use of simulations by the students by combining cognitive and affective factors. |
| High fidelity simulations Enhanced fidelity of an instructional simulation has positive effects on the learner outcome. |
| Multiple representations Interfaces which use multiple representations offer valuable information which facilitates problem solving strategies. |
| Low complexity simulations Low complexity simulations are better suited to novice learners. |
| Set of guide-lines for the design of computer simulations, and within the constraints of a research of this type an interface design syntax. |

Table 10.1. Summary of the contributions of this thesis.

10.5. Limitations and Criticisms

One basic limitation of this research was that the time constraints of a doctoral research did not allow studies with a greater number of fidelity and complexity variations. These would include manipulations of the underlying model, experimenting for instance with environments like Gravitas (Chapter Three), where the complexity is task dependent, because the number of variables and the equations for a problem depend on the combination of MassObs used, and the conditions. The results of a more representative and comprehensive study of points on the fidelity-complexity space would potentially produce a wider range of findings.

Complete transcription analysis was carried out only on a sample of interactions (1/2 of the pairs were presented in an annotated transcript), but the whole of the interactions were studied to detect similarities and trends.

This research may overstate the importance of graphical representations, since they play a significant role in physics simulations, probably bigger than in other domains, so outcomes of the studies are only transferable with caution to other simulations with different domains.

Extreme simplifications like screens devoid of any complementary information (graphs, digital counters, graphs, buttons etc.), which one could argue alter the value of fidelity, were not attempted since research has shown that visual aids and multiple representations help make the underlying model visible. Additionally multiple

representations translate the physical reality into readable models and enhance the learner's control in operating in the simulation. Potential implications though of the effect of a screen charged with "extraneous" perceptual aids on students' perception of reality cannot be denied and need further investigation.

10.6. Further scope

Future studies concerned with the design of simulations would benefit from investigating a number of issues related to this research, namely: student modelling, dynamic fidelity and complexity, and such interface issues as the use of colour, sound, text and navigation.

10.6.1. Student modelling

It must be pointed that this research was not concerned primarily with student modelling based environments. This type of research would be rewarding by encouraging students to create their own models. There are recent accounts of researchers which indicate that acceptance of the design of interactive interfaces is not possible without involvement of the end user in the complete design process (Webb, 1994; Rappin, 1997).

10.6.2. Sequences of simulations

Another interesting issue is the use of sequences of simulations. The use of combined scenarios of decreasing or increasing fidelity or complexity, or presenting the user simultaneously with variations of

fidelity and letting her to explore them are related to the issue of dynamic fidelity or complexity.

One research direction would be to investigate what happens if the learners use simulations presented in a specific sequence, e.g. from high to low fidelity or complexity, or vice versa. These sequences may help the users to move successfully between reality and the desired abstraction of the physical model.

For instance, the following example would investigate the use of sequences of simulations, where the two variables of fidelity and complexity have binary values of high and low. The four combinations of fidelity complexity in this case are given in Table 10.2:

| Fidelity Complexity combinations | |
|----------------------------------|-------------------------------|
| 1 | low complexity/low fidelity |
| 2 | high complexity/low fidelity |
| 3 | low complexity/high fidelity |
| 4 | high complexity/high fidelity |

Table 10.2. Four categories of fidelity complexity simulations.

In this case potential sequences of simulations are presented in Table 10.3. As an example the first sequence 1 ➡ 2 could be carried out in a low fidelity environment by increasing the complexity of the underlying model from low to high when the users have familiarised themselves with the low complexity simulation etc.

| Simulation Sequences |
|----------------------|
| 1 ➡ 2 |
| 3 ➡ 4 |
| 1 ➡ 2 ➡ 4 |

Table 10.3. Examples of sequences of simulation from Table 10.2.

10.6.3. Alternate realities

Another interesting issue is the use of alternate realities. Research has been done on the conceptual changes resulting from the students' attempts to match simulations to reality (Smith, 1987; Hennessy, 1993). Hennessy (1993) suggests two ways to achieve that: either by "offering the students a range of simulations and ask them to select that one which most accurately maps onto reality as they see it", or by allowing the students to "make the functioning of a certain physical law itself a parameter to be adjusted by the students and ask them to produce the setting for that parameter which best matches the real world". The first could be translated in terms of fidelity: offering the students a range of degrees of fidelity and ask them to select that one which most accurately maps onto reality as they see it, and in terms of complexity as: "offering the students a range of degrees of complexity and ask them to select that one which most accurately maps onto reality as they see it". The second one could only have a complexity application: make complexity itself (e.g. level of precision of physical theory or number of variables used) a parameter to be adjusted by the students and ask them to produce the setting for that complexity value which best matches the real world.

10.6.4. Interface syntax

Considerations of the interface syntax should take into account the use of colour, sound and text and navigation which were beyond the focus of this work. The use of colour is dependent on the fidelity level of the simulation. It is not absolutely necessary for low fidelity simulations; circles, squares and other forms of physical representation, like vectors and units, will not necessarily be enhanced by the use of colour. However, sometimes the use of colour in physical objects and a coloured background can have a motivational effect to the users, making the interaction of the simulation more attractive. Colour in low fidelity simulations can also be useful when it contributes to making the interface clearer to the user. For instance, when there is a large number of physical objects on the computer screen and the designer uses colour to highlight some objects to attract the user's attention.

In medium and high fidelity simulations the use of colour is more important since the use of appropriate realistic colouring creates credible representations of real world objects. It cannot be claimed that credible representations of the real world are created if a basic attribute of it, colour, is missing. In high fidelity simulations, the use of video dictates the use of colour in coloured video excerpts (as in MM, Chapter Seven) which otherwise would in most cases look "grey" and fuzzy.

The appropriate use of sound and/or text should also be investigated. Cases where the students can look up definitions and the relevant theory in the form of a tutorial on a computer screen (like in MM)

offer the possibility to the users to browse, skim or read in detail as an extra option to the simulation and offers more control. Sound, though motivational for younger children, is not absolutely necessary for older students (A level students, like the users of these studies were, or university students).

Extensive research has been done on navigation issues in multimedia environments. It should be investigated if navigation is as essential for simulations. Simulations have easy to use one-level (the display where the simulation takes place) or two-level interfaces (the display and multiple representations). In simulations it is more the case of designing interfaces well rather than emphasising how to travel to and fro between levels of information.

10.7. Summary

This thesis focused on the use and design of computer simulations. An effort was made to put simulations in the context of CAL as a whole, and to discuss their use in science. An annotated bibliography on computer simulations as software and on their use in an instructional setup was kept. This was followed by the description of a taxonomy of the factors that constitute a successful simulation, with an emphasis on the interface and the underlying model as significant factors for communicating the disciplinary approach to learners. A set of descriptors was tested as well as a research methodology which proved useful for studying interaction with computer simulations.

The research accepted the view that students' interactions with simulations can help in promoting conceptual learning and focused

on investigating which features of a simulation facilitate learning. To this aim it was attempted to answer the question "What constitutes a successful simulation?" Structured experiments based on instructional cycles outlined by researchers so far provided the appropriate framework which would ensure that simulations were used constructively.

The data from a number of studies of interactions with simulations were analysed. The findings were presented and it was described what they reveal about the way students use and perceive simulations. Finally a set of guidelines for the design of computer simulations was given, and within the constraints of research of this type also an interface design syntax.

References

Adams, A., Sasse, M., & Lunt, P. (1997). *Making passwords secure and usable*. In H. Thimbleby, B. O'Conaill, & P. Thomas (Eds.), *People and Computers XII* London: Springer-Verlag.

Alessi, S. (1988). *Fidelity in the Design of Instructional Simulations*. *Journal of Computer-Based Instruction*, 15(2), 40-47.

Allen, J. A., Hays, R. T., & Buffardi, L. C. (1986). *Maintenance training simulator fidelity and individual differences in transfer of learning*. *Human Factors*, (28), 497-509.

Andaloro, G. (1991). *A computer-based diagnostic tutor for average velocity*. *Computers and Education*, 17(3), 227-234..

Balzano, E., Guidoni, P., Moretti, M., Sassi, E., & Squeglia, G. (1992). *Introductory University Courses and Open Environment Approaches: the Computer as a Multi-Role Mediator in Teaching/Learning Physics*. In A. Tiberghien & H. Mandl (Eds.), *Intelligent Learning Environments and Knowledge Acquisition in Physics* (pp. 5-19). Berlin: Springer-Verlag.

Baum, D. R., Smith, D. A., Hirshfeld, S. F., Klein, G. A., Sweezey, R. W., & Hays, R. T. (1982). *Specification of training simulator fidelity: A research plan* (ERIC Document Reproduction service No. ED 241 793).

- Berger, C. F., Lu, C. R., Belzer, S. J., & Voss, B. E. (1994). *Research in the uses of technology in science education*. In D. L. Gabel (Eds.), *Handbook of research on science teaching and learning* (pp. 598). New York: Macmillan Publishing Company.
- Borghi, L. (1991). *Practical use of simulations to study relative motion*. *Computers Education*, 16(2), 157-166.
- Borghi, L. (1992). *Computer simulation of historical experiments and understanding of physics concepts*. In A. Tiberghien & H. Mandl (Eds.), *Intelligent Learning Environments and Knowledge Acquisition in Physics* (pp. 206-215). Berlin: Springer-Verlag.
- Brown, J. S., Collins, A., & Duguid, P. (1989). *Situated cognition and the culture of learning*. *Educational Researcher*.
- Caillot, M. (1992). *The design and learning environment in mechanics: two case studies*. In A. Tiberghien & H. Mandl (Eds.), *Intelligent Learning Environments and Knowledge Acquisition in Physics* (pp. 216-228). Berlin: Springer-Verlag.
- Champagne, A. B., Klopfer, L. E., & Anderson, J. H. (1980). *Factors influencing the learning of classical mechanics*. *American Journal of Physics*, 48(12), 1074-1079.
- Christel, M. G. (1994). *The Role of Visual Fidelity in Computer-Based Instruction*. *Human-Computer Interaction*, 9, 183-223.

Clark, A. (1993). *Investigating school physics laboratory software and hardware*. *Physics Education*, 28(2), 87-91.

Csikszentmihalyi, M. (1990). *Literacy and Intrinsic Motivation*. *Daedalus, Journal of the American Academy of Arts and Sciences*, 119(2), 115-140.

Cunningham, J. B. (1984). *Assumptions underlying the use of different types of simulations*. *Simulations & Games*, (15), 213-234.

deHoog, R., deJong, T., & deVries, F. (1991). *Interfaces for instructional use of simulations*. *Education and Computing*, 6(3, 4), 359-385.

deJong, T. (1991). *Learning and instruction with computer simulations*. *Education and Computing*, 6(3, 4), 217-229.

diSessa, A. A. (1982). *Unlearning Aristotelian Physics: A Study of Knowledge-Based Learning*. *Cognitive Science*, 14(6), 37-75.

diSessa, A. A. (1986). *Artificial worlds and real experience*. *Instructional Science*, 14, 207-227.

Draper, S. W. (1991). *Design considerations in a project on conceptual change in science*. *Computers and Education*, 17(1), 37-40.

Draper, S., Mohamed, R., Byard, M., Driver, R., Hartley, R., Mallen, C., Twigger, D., O'Malley, C., Hennessey, S., O'Shea, T., Scanlon, E., & Spensley, F. (1992). *Conceptual Change in Science. Final Report to*

ESRC. March 1992 (CALRG Technical Report No. 123). The Open University.

Driver, R. (1989). *Students' conceptions and the learning of science*. International Journal of Science Education, 11(5), 481-490.

Finlay, D., & Lamb, M. J. (1993). *Microcomputers in the physics laboratory*. Physics Education, 28(3), 92-101.

Goodyear, P. A. (1991). *Knowledge-based approach to supporting the use of simulation programs*. Computers and Education, 16(1), 99-103.

Grimellini-Tomasini, N., Pecori-Balandi, B., Pacca, J. L. A., & Villani, A. (1993). *Understanding conservation laws in mechanics: Students' conceptual change in learning about collisions*. Science Education, 77(2), 169-189.

Gunstone, R. F. (1988). *Learners in Science Education*. In P. Fensham (Eds.), *Development and Dilemmas in Science Education* (pp. 318). London: The Falmer Press.

Hartley, J. R. L., & Misell, D. L. (1987). *Physics by experiment an Advanced-Level course*.

Hatzipanagos, S. (1992). *A comparison of 16-19 Physics education in Greece and in England*. MSc dissertation, Reading University.

Hatzipanagos, S. (1995a). *Fidelity and complexity: Dimensions in the*

study of reality and abstractions in computer simulations. In D. Jonassen & G. McCalla (Ed.), *International Conference in Computers in Education*, (pp. 105-110). Singapore: Association for the Advancement of Computing in Education.

Hatzipanagos, S. (1995b). *Simulations for physics learners*, Paper presented at the Institute of Physics, Education Group Annual Conference, 10-12 April 1995, Cambridge.

Hatzipanagos, S. (1995c). *Simulations for physics learners: Reality versus Abstraction*. Paper presented at CAL 95, 10-13 April, Cambridge.

Hatzipanagos, S. (1997a). *Aspects of reality and abstraction in interactive learning environments*, Doctoral workshop. In *Human Computer Interaction 1997*, August 12-15, Bristol.

Hatzipanagos, S. (1997b). *Fidelity and complexity: Multimedia Motion in Action*. Paper presented at CAL97, March 23-26, Exeter.

Hatzipanagos, S., Scanlon, E., & Li, Y. (1997c). *Typologies of interface design which provide effective support for learning physics*. Paper presented at ALT-C, Wolverhampton.

Hays, R. T. (1980). *Simulator fidelity: A concept paper* (Technical No. 490). U.S. Army Research Institute.

Hazari, S. I., & Reaves, R. R. (1994). *Students preferences toward microcomputer user interfaces*. *Computers and Education*, 22(3), 225-229.

Hennessey, S., Spensley, F., O'Malley, C., Byard, M., Driver, R., Mallen, C., O'Shea, T., & Scanlon, E. (1989). *A Direct Manipulation Microworld for Vertical Motion* (CITE No. 92). Open University.

Hennessey, S., & O'Shea, T. (1993). *Learner perceptions of realism and magic in computer simulations*. *British Journal of Educational Technology*, 24(2), 125-138.

Hodson, D. (1993). *Re-thinking Old Ways: Towards A More Critical Approach To Practical Work In School Science*. *Studies in Science Education*, (22), 85-142.

Howe, C. (1991). *Explanatory concepts in physics: towards a principled evaluation of teaching materials*. *Computers and Education*, 17(1), 73-80.

Jacques, R. (1995). *Using Engagement to Evaluate Hypermedia*. Position Paper presented at CHI '95 Research Symposium.

Jones, A., Tosunoglu, C., Scanlon, E., Butcher, P., Ross, S., Greenberg, J., & P.Murphy (1997). *An evaluation framework for educational software*. Paper submitted to *Interacting with Computers*.

Issroff, K. (1992). *Computer-Assisted Cooperative Learning* (CITE No. 183). Open University.

Kahn, B. (1985). *Computers in Science*. Cambridge: Cambridge University Press.

Laurilllard, D. (1992). *Learning through collaborative computer simulations*. British Journal of Educational Technology, 23(3), 164-171.

Laurilllard, D. (1993). *Rethinking university teaching*. London: Routledge.

Levin, J. A., & Waugh, M. (1988). *Educational simulations, tools, games, and microworlds: computer-based environments for learning*. International Journal of Educational Research, 12, 71-79.

Lewis, R. A. (1991). *Computer assignments and problems classes for physics students*. Computers Educ, 16(4), 349-362.

Linder, C. J., & Erickson, G. L. (1989). *A study of tertiary physics students' conceptualizations of sound*. International Journal of Science Education, 11(5), 491-501.

Lunetta, V., & Hofstein, A. (1991). *Simulation and laboratory practical activity*. In B. E. Woolnough (Eds.), Practical Science Open University Press.

Malone, T. W. (1981). *What makes computer games fun?* BYTE, 6(2), 258-277.

Mayes, J. T., & Fowler, C. J. *Learning Technology and usability: a framework for understanding courseware*. Internal paper, Glasgow Caledonian University.

McClelland, J. A. G. (1985). *Misconceptions in mechanics and how to avoid them*. *Physics Education*, (20), 159-162.

McDermott, L. C. (1992). *Research as a guide for the design of intelligent learning environments*. In A. Tiberghien & H. Mandl (Eds.), *Intelligent Learning Environments and Knowledge Acquisition in Physics* (pp. 245-264). Berlin: Springer-Verlag.

Nielsen, J. (1993). *Usability Engineering*. London: Academic Press Limited.

O'Malley, C., Draper, S., & Riley, M. (1985). *Constructive interaction: A method for studying human-computer interaction*. In B. Shackel (Eds.), *Human-Computer Interaction - Interact '84* Amsterdam: North Holland.

Pride, A. (1993). *Computer-assisted learning- a biological simulation*. In D. Bentley & M. Watts (Eds.), *Learning and teaching in school science: Practical alternatives*. Milton Keynes: Open University Press.

Rappin, N., Guzdial, M., Realff, M., & Ludovice, P. (1997). *Balancing Usability and Learning in an interface*. In CHI 97, In CHI 97, Atlanta, GA, USA.

Reigeluth, C. M., & Schwartz, E. (1989). *An Instructional Theory for the Design of Computer-Based Simulations*. *Journal of Computer-Based Instruction*, 16(1), 1-10.

Robinson, E. S. (1927). *The "similarity" factor in retroaction*. American Journal of Psychology(39), 297-312.

Roschelle, J., & Clancey, W. J. (1992). *Learning as Social and Neural*. Educational Psychologist, 27(4), 435-453.

Roschelle, J. (1994). *Designing for cognitive communication: epistemic fidelity or mediating collaborative inquiry*. The Arachnet Electronic Journal on Virtual Culture, 2(2).

Scaife, J., & Wellington, J. (1993). *Information Technology in Science and Technology Education*. Buckingham: Open University Press.

Scanlon, E. (1993). *Running in the rain: using a shared simulation to solve open-ended physics problems*. Physics Education 28(2), 107-113..

Scott, L. (1993). *Playing games in Physics*. In D. Bentley & M. Watts (Eds.), *Learning and teaching in school science: practical alternatives*. Milton Keynes: Open University Press.

Sellman, R. (1991). *Hooks for Tutorial Agents: A note on the design of Discovery Learning Environments (CITE No. 145)*. The Open University.

Sellman, R. (1992). *Gravitas: A Discovery Learning Environment for Newtonian Gravitation (CALRG No. 110)*. Open University.

Sellman, R. (1994) *Objectworlds: A Class of Computer-Based Discovery Learning Environments*. Unpublished Doctoral Thesis, The Open University.

Shneiderman, B. (1987). *Designing the User Interface: Strategies for Effective Human-Computer Interaction*. Reading, MA: Addison-Wesley.

Sinclair, J. (Ed.). (1993). *BBC English Dictionary*. London: HarperCollins.

Smith, R. B. (1987). *An Example of the Tension Between Literalism and Magic*. In CHI+GI 1987.

Spensley, F., O'Shea, T., Singer, R., Hennessy, S., Malley, C. O., & Scanlon, E. (1990). *An 'Alternate Realities' Microworld for Horizontal Motion* (CITE No. 105). Open University.

Squires, D., & Preece, J. (1996). *Usability and learning: evaluating the potential of educational software*. *Computers and Education*, 27(1), 15-22.

Tamir, P. (1991). *Practical work in school science : an analysis of current practice*. In B. E. Woolnough (Eds.), *Practical Science* Open University Press.

Tao, P. K., Tse, M. W., & Yu, C. K. (1993). *Developing CAL programs for schools physics*. *Physics Education*, 28(3), 178-184.

Teodoro, V. D. (1994). Learning with Computer-Based Exploratory Environments in Science and Mathematics. In S. Vosniadou, E. DeCorte, & H. Mandl (Eds.), *Technology-Based Learning Environments Psychological and Educational Foundations* (pp. 26-32). Berlin: Springer-Verlag.

Thornton, R. K. (1992). *Enhancing and evaluating students' learning of motion concepts*. In A. Tiberghien & H. Mandl (Eds.), *Intelligent Learning Environments and Knowledge Acquisition in Physics* (pp. 265-283). Berlin: Springer-Verlag.

Twigger, D., Byard, M., Draper, S., Driver, R., Hartley, R., Hennessy, S., Mallen, C., Mohamed, R., O'Malley, C., O'Shea, T., & Scanlon, E. (1991). *The Conceptual Change in Science project*. *Journal of Computer Assisted Learning*, 7(2), 144-155.

Viennot, L. (1985). *Analysing students' reasoning: Tendencies in interpretation*. *American Journal of Physics*, 53(5), 432-436.

Watson, D. M. (1993). *Classroom Processes and Geography Simulations*. *Computers and Education*, 21(1/2), 9-16.

Webb, M. (1994). *Learning by Building Expert System Models*. In H. Mellar, J. Bliss, R. Boohan, J. Ogborn, & C. Tompsett (Eds.), *Learning with Artificial Worlds: Computer Based Modelling in the Curriculum*. London: The Falmer Press.

Welford, G., Bell, J., Davey, A., Gamble, R., & Gott, R. (1983). *APU Science in schools: age 15* (Research Report No. 4).

Wellington, J. J. (1985). *Children, Computers and the Curriculum*. Harper & Row Publishers.

Wenger, E. (1987). *Interactive simulations: communicating mental models*. In *Artificial Intelligence and Tutoring Systems* (pp. 79-100). Los Altos, California: Morgan Kaufmann publishers.

Whalley, P. (1995). *Imagining with Multimedia*. *British Journal of Educational Technology*, 26(3), 190-204.

White, R. T., & Gunstone, R. F. (1989). *Metalearning and conceptual change*. *International Journal of Science Education*, 11(Special Issue), 577-586.

White, B. Y. (1992). *A Microworld-Based Approach to Science Education*. In E. Scanlon & T. O. Shea (Eds.), *New Directions in Educational Technology* Berlin: Springer-Verlag.

Whitelegg, E., Scanlon, E., & Hatzipanagos, S. (1997). *Multimedia Motion - Motivating Learners*. *ALT-J*, 5(1), 65-69.

Whitelock, D., Taylor, J., O'Shea, T., Scanlon, E., Sellman, R., & O'Malley, C. (1991). *Collaboratively Debugging Shared Models for Energy Conservation using a Computer Simulation* (CITE No. 136). The Open University.

Whitelock, D., O'Shea, T., Taylor, J., Scanlon, E., Clark, P., & O'Malley, C. (1993a). *The Interaction Between Group Composition and*

Computer Supported Collaborative Learning (CITE No. 180). The Open University.

Whitelock, D., O'Shea, T., Taylor, J., Scanlon, E., Clark, P., & O'Malley, C. (1993b). *Conflict versus Co-operation? How does Group Composition affect Computer Supported Collaborative Learning in Physics?* (Technical report No. 93/16). The Open University.

Whitelock, D., Taylor, J., O'Shea, T., Scanlon, E., Clark, P., & O'Malley, C. (1993c). *Challenging Models of Elastic Collisions with a Computer Simulation*. *Journal of Computers in Education*, 20(1), 1-9.

Whitelock, D., & Scanlon, E. (1996). *Motivation, media and motion: Reviewing a Computer Supported Collaborative Learning Experience* (CITE No. 226). Open University.

Williges, B. H., & Roscoe, S. N. (1973). *Synthetic flight training revisited*. *Human Factors*, (15), 543-560.

Wolfe, J. (1985). *The teaching effectiveness of games in collegiate business courses: A 1973-1983 update*. *Simulation & Games*, 16(3), 251-288.

Participants of the case studies

Gravitas, Multimedia Motion/pilot

| | | |
|--|-------------------------------------|------------------------------------|
| P1 Tassos PhD research student | | |
| P2 Ben PhD research student | | |
| P3 Brenda University lecturer | | |
| P4 Kevin PhD research student | | |
| P5 Li A level student | P6 Darren A level student | |
| P7 Gabriel A level student | P8 John A level student | P9 Steve A level Student |

ColaCollision (CoC)

| | |
|---|--|
| P10 Vanessa University lecturer | P11 Derek University lecturer |
| P12 Harry PhD research student | P13 Mick PhD research student |
| P14 Elisa PhD Research Student | P15 Sara University researcher |
| P16 Pete University lecturer | P17 Janet PhD research student |

Multimedia Motion (MM)

| | |
|-------------------------------------|-------------------------------------|
| S1 Daniel A level student | S2 Robert A level student |
| S3 Barry A level student | S4 Judith A level student |
| S5 Nora A level student | S6 Irene A level student |
| S7 Duncan A level student | S8 Jeremy A level student |
| S9 Roger A level student | S10 Ray A level student |
| S11 Agnes A level student | S12 Simon A level student |

CirclesColliding (CC)

CC1

| | |
|---------------------------------------|---------------------------------------|
| S13 Mike A level student | S14 Carol A level student |
| S15 Anthony A level student | S16 Martin A level student |
| S17 Helen A level student | S18 Rosie A level student |
| S19 Gordon A level student | S20 Peter A level student |
| S21 Patrick A level student | S22 Matthew A level student |
| S23 Philip A level student | S24 Nigel A level student |

CC2

| | |
|--|--|
| S25 Maria University researcher | S26 Rick PhD research student |
|--|--|

Appendix 1

Questionnaires and worksheets

- Gravitas/MM-pilot 1
 - Gravitas 1
 - Q1: Pre test questionnaire 1
 - I: Using Gravitas 4
 - Q2: Post test questionnaire 5
- ColaCollision..... 7
 - Q1: Pre test questionnaire 7
 - W: Interaction worksheet..... 10
 - Q2: Post test questionnaire 11
- Multimedia Motion..... 13
 - Q1: Pre test Questionnaire 13
 - W: Interaction worksheet..... 15
 - Q2: Post test questionnaire 16
- Circles Colliding 18
 - CC1..... 18
 - Q1: Pre test Questionnaire 18
 - W: Interaction worksheet..... 20
 - Q2: Post test questionnaire 22
 - CC2..... 24
 - CC2 questionnaire..... 24

Gravitas/MM-pilot

Gravitas

Q1: Pre test questionnaire

Name.....

Age

Male/Female.....

Have you got any previous experience with computers (e.g. for word-processing)? yes/no.

If yes give some examples of your experience.

What sort of science courses have you done in school?

Have you ever used a computer simulation?

Yes/no

If yes, explain and say what you think a computer simulation is.

How do you think that a computer simulation of a physical phenomenon or an experiment could be useful?

What is meant by a conservation law? Can you give any further examples of conservation laws?

Why do you think the moon moves in an orbit around the earth?

In 1969 two Americans were the first people to land on the moon and return safely to earth. As planned they had used all their fuel when they had completed only one seventh of the journey back to earth. Why do you think the spaceship needed only this amount of fuel to get them back to earth?

I: Using Gravitas

What do you think will happen when we start the system?

Try to find a combination of velocities (x and y) that would make the MassOb moon to orbit the MassOb earth.

Is there a better way of doing it instead of using trial and error?

How could we calculate the correct velocity of the moon around the earth. Would this be the x or y velocity?

Do you notice anything about the display on the screen?

Why does the system you have built moves up or down the screen?

What could we change in the system's data to eliminate this movement?

Can you explain why the system is staying now in one place?

Q2: Post test questionnaire

Have you anything else to add or change in the way you answered before the two questions:

Why do you think the moon moves in an orbit around the earth?

In 1969 two Americans were the first people to land on the moon and return safely to earth. as planned they had used all their fuel when they had completed only one seventh of the journey back to earth. Why do you think the spaceship needed only this amount of fuel to get them back to earth?

Comparing Gravitas with the behaviour of masses in space do the objects in Gravitas behave like two similar masses in the real world? If not, What do you think is the difference?

What do you think of Gravitas? How satisfactory do you think the interface (what you see on the computer screen) is?

How satisfied are you with how you used the simulation?

Do you think that working with Gravitas helps to understand better gravitational forces and motion in space? Explain.

ColaCollision

Q1: Pre test questionnaire

Name.....

Age

Male/Female.....

Have you got any previous experience with computers (e.g. for word-processing)? (yes/no). If yes give some examples of your experience.

What sort of science courses have you done in school?

Have you ever used a computer simulation?

Yes/no

If yes, explain and say what you think a computer simulation is.

Can you say what is meant by a conservation law? Can you give any examples of conservation laws?

Now try these questions about collisions:

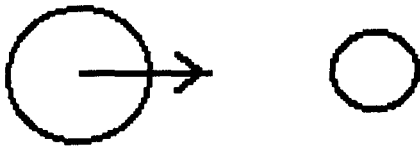
1. If you have two equal masses moving at the same speed and colliding what will happen after the collision?



2. If a small mass collides with a much bigger immobile mass what will happen after the collision?



3. If a big mass collides with a small immobile mass what will happen after the collision?



W: Interaction worksheet

Plan and carry out an experiment which could show in ColaCollision the conservation of momentum. Carry out this experiment using ColaCollision.

If you want to send the boxes travelling away from each other at the same speed, what initial conditions are needed: what masses of boxes must we use, what initial speed (if any) must the boxes have?

If you want to make one box stop after impact what initial conditions are needed: what masses of boxes must we use, what initial speed (if any) must the boxes have?

Can you say what is meant by a conservation law? Can you give any examples of conservation laws?

Q2: Post test questionnaire

Now try again these questions about collisions:

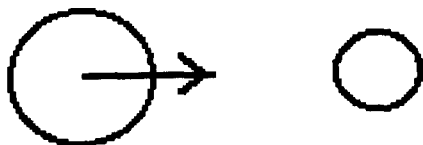
If you have two equal masses moving at the same speed and colliding what will happen after the collision?



If a small mass collides with a much bigger immobile mass what will happen after the collision?



If a big mass collides with a small immobile mass what will happen after the collision?



What do you think of ColaCollision? How satisfactory do you think the interface (what you see on the computer screen) is?

If you were repeating the experiments now, would you change anything in the way you carried them out.

How satisfied are you with how you used the simulation?

What do you feel you have learnt after using the simulation?

Do you think that working with ColaCollision helps to understand better conservation laws and collisions? Yes/No

If yes can you say how?

Multimedia Motion

Q1: Pre test Questionnaire

Have you got any previous experience with computers (e.g. for word-processing)? yes/no. If yes give some examples of your experience.

What sort of science courses have you done in school?

Have you ever used a computer simulation? (Yes/no). If yes, explain and say what you think a computer simulation is.

Can you say what is meant by a conservation law? Can you give any examples of conservation laws?

Now try these questions about collisions:

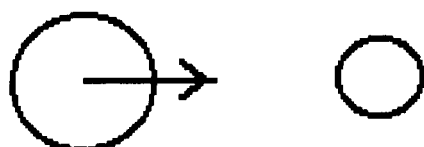
1. If you have two equal masses moving at the same speed and colliding what will happen after the collision?



2. If a small mass collides with a much bigger immobile mass what will happen after the collision?



3. If a big mass collides with a small immobile mass what will happen after the collision?



W: Interaction worksheet

Collision 1: Explore the sequence and see if you can measure the velocities of the objects before and after the collision.

What might happen to both momentum and kinetic energy in this kind of collision?

Collision 4: Use the sequence to measure how the momentum and kinetic energy of the two gliders change in the collision. Try measuring the velocities involved and deducing what happens to the momentum and kinetic energy for each of the gliders.

Collision 1, 4 and 5: Try making measurements that will help you decide how the speed of the immobile mass (target) after the collision depends on the speed of the other one (projectile) before it and how it depends on their relative masses.

Q2: Post test questionnaire

Now try again these questions about collisions:

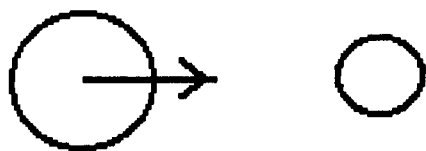
If you have two equal masses moving at the same speed and colliding what will happen after the collision?



If a small mass collides with a much bigger immobile mass what will happen after the collision?



If a big mass collides with a small immobile mass what will happen after the collision?



In sport activities the ball is often (but not always) much lighter than whatever is used to hit it. If you were asked to design a more effective baseball bat would it be heavy or light? Can a lightweight soccer player kick a ball as fast as a heavy one?

Snooker or pool players can play a shot which results in the cue ball stopping as a result of a collision. How fast do you think the target ball moves after the collision?

How satisfied are you with how you used the MM CD ROM?

What do you feel you have learnt after using the MM CD ROM?

Do you think that working with Multimedia Motion helps to understand better conservation laws and collisions? (Yes/No). If yes can you say how?

Circles Colliding

CC1

Q1: Pre test Questionnaire

Have you got any previous experience with computers (e.g. for word-processing)? yes/no. If yes give some examples of your experience.

What sort of science courses have you done in school?

Have you ever used a computer simulation? Yes/no. If yes, explain and say what you think a computer simulation is.

Can you say what is meant by a conservation law? Can you give any examples of conservation laws?

Now try these questions about collisions:

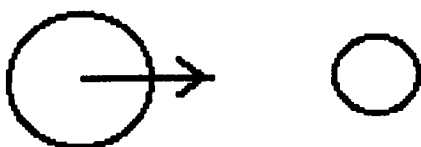
1. If you have two equal masses moving at the same speed and colliding what will happen after the collision?



2. If a small mass collides with a much bigger immobile mass what will happen after the collision?



3. If a big mass collides with a small immobile mass what will happen after the collision?



W: Interaction worksheet

Collision 1: Explore the sequence and see if you can measure the velocities of the objects before and after a collision. What might happen to both momentum and kinetic energy in this kind of collision?

Collision 2: Use the sequence to measure how the momentum and kinetic energy of the two masses change in the collision.

Collisions 1, 2 and 3: Try making measurements that will help you decide how the speed of the immobile mass (target) after the collision depends on the speed of the other one (projectile) before it and how it depends on their relative masses.

Q2: Post test questionnaire

Now try again these questions about collisions:

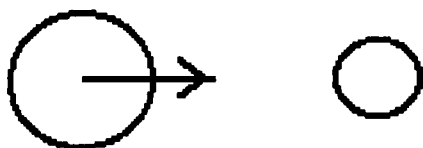
If you have two equal masses moving at the same speed and colliding what will happen after the collision?



If a small mass collides with a much bigger immobile mass what will happen after the collision?



If a big mass collides with a small immobile mass what will happen after the collision?



What do you think of the CirclesColliding simulations? How satisfactory do you think the interface (what you see on the computer screen) is?

How satisfied are you with how you used the CirclesColliding ?

What do you feel you have learnt after using the CirclesColliding simulations?

Do you think that working with CirclesColliding helps to understand better conservation laws and collisions? Yes/No. If yes can you say how?

CC2

CC2 questionnaire

If you have two equal masses moving as in fig 1, can you say what will be the outcome of the collision.

What initial speed these two masses must have in order to change direction of motion (from moving on the x-axis to the y-axis and vice versa) after the collision.

What is the minimum speed the masses must have in order to collide?

Appendix 2

Gravitas, Multimedia Motion/pilot

| | |
|--|----|
| Gravitas..... | 1 |
| Q1: Answers to the pre test questionnaire..... | 1 |
| I: Using Gravitas..... | 3 |
| Q2: answers to the post test questionnaire..... | 5 |
| T: Samples Interaction Transcripts..... | 8 |
| P1: Ben | 8 |
| P2: Brenda | 12 |
| Multimedia Motion..... | 16 |
| P7: Gabriel, P8: John and P9: Steve | 16 |
| Q2: Answers to the post test questionnaire | 18 |

Participants

| | | | |
|----|---------|----|--------|
| P1 | Tassos | | |
| P2 | Ben | | |
| P3 | Brenda | | |
| P4 | Kevin | | |
| P5 | Li | P6 | Darren |
| P7 | Gabriel | P8 | John |
| | | P9 | Steve |

Gravitas

Q1: Answers to the pre test questionnaire

Have you got any previous experience with computers (e.g. for word-processing)? yes/no.

If yes give some examples of your experience.

P1. Yes. programming (scientific) and general interaction with various systems.

P2. Extensive knowledge of UNIX and DOS, and a working knowledge of VMS. Able to program in Basic, FORTRAN, C, and 68000 Assembly language. Until now no experience with Apple Macs.

P3. I use a personal computer mainly for word processing and communication purposes. I have very rusty programming experience (FORTRAN, punched cards and main frame computers and some passing acquaintance with LOGO).

What sort of science courses have you done in school?

P1. I have a physics degree.

P2. O levels, A level, honours degree, PhD.

P3. A little. A long time ago I obtained a PhD. in Physics and taught in a Poly. I have a research physics education, writer of teaching material for science teachers and I teach physics in the OU Physics foundation course summer school. However most of my physics is very rusty.

Have you ever used a computer simulation?

Yes/no

If yes, explain and say what you think a computer simulation is.

P1. It can provide an opportunity to repeat the experiment several times, change various conditions study in detail and peace of mind problems that the on-line analysis would otherwise be impossible or difficult.

P2 . Predicting results of experiments either not yet performed (to decide if it is worth doing) or impossible to perform (e.g. cooling of infra-red space telescopes by purely radiative methods). Also useful to check current theories by seeing if the answers are correct.

P3. A computer programme which facilitates a simulation or model of a real situation. If it is interactive a user can vary conditions and parameter to see how the situation changes.

How do you think that a computer simulation of a physical phenomenon or an experiment could be useful?

P3. It could allow me to do an experiment of experience a phenomenon which otherwise would be difficult to do. I would allow me to manipulate things to see and feel how situations could vary and behave differently.

What is meant by a conservation law? Can you give any further examples of conservation laws?

P3. Within a closed system, the total linear momentum of a group of objects remains the same.

Why do you think the moon moves in an orbit around the earth?

P1. Due to gravitational attraction.

P2. Cos the centrifugal force of the orbit balances the gravitational pull of the earth.

P3. Because of the relationship between the gravitational fields and the angular velocity of the earth and moon.

In 1969 two Americans were the first people to land on the moon and return safely to earth. As planned they had used all their fuel when they had completed only one seventh of the journey back to earth. Why do you think the spaceship needed only this amount of fuel to get them back to earth?

P1. After that point the gravitational attraction of the earth would serve as "fuel" (the moon attraction being less than the earth attraction after that point).

P2. Cos from there on gravity did the rest.

P3. By that stage they must have re-entered the earth's gravitational field and could return to earth otherwise unassisted.

I: Using Gravitas

What do you think will happen when we start the system?

P1. The two objects will start moving towards each other.

P2. Collision!

Try to find a combination of velocities (x and y) that would make the MassOb moon to orbit the MassOb earth.

Is there a better way of doing it instead of using trial and error?

How could we calculate the correct velocity of the moon around the earth. Would this be the x or y velocity?

Do you notice anything about the display on the screen?

P1. Yes, the earth is also moving and is not kept stationary at the centre of the circle. Thus, the moon is not doing the same circle all the time.

Why does the system you have built moves up or down the screen?

What could we change in the system's data to eliminate this movement?

Can you explain why the system is staying now in one place?

P1. In order to maintain its total momentum at zero.

P2. The total momentum of the system is zero.

Q2: answers to the post test questionnaire

Have you anything else to add or change in the way you answered before the two questions:

Why do you think the moon moves in an orbit around the earth?

P1. As well to satisfy the momentum conservation.

P2. No.

P3. Because of the relationship between the gravitational fields and the angular velocity of the earth and moon.

In 1969 two Americans were the first people to land on the moon and return safely to earth. as planned they had used all their fuel when they had completed only one seventh of the journey back to earth. Why do you think the spaceship needed only this amount of fuel to get them back to earth?

P1. No.

P2. No.

P3. By that stage they must have re-entered the earth's gravitational field and could return to earth otherwise unassisted.

Comparing Gravitas with the behaviour of masses in space do the objects in Gravitas behave like two similar masses in the real world? If not, What do you think is the difference?

P1. Interferences from a number of other real bodies are also present in the real case.

P2. For the real earth-moon system, many other bodies are present (all the planets, moons asteroids and the sun). Also the earth is itself in orbit around the sun. All these things make the real system considerably more complicated. the orbits on the screen are circular, in reality they are elliptical.

it's different from a real system because in space a body moves under the influence of a big number of other masses, it's not isolated.

P3. It's not representative of the real system because the moon's orbit around the earth is not circular but elliptical. An elliptical orbit would be a truer representation. The other planets' effect is minimal.

I used things that I know about the real system in order to make calculations to put in there in order to make calculations to put in there. It's like building systems using the real data.

What do you think of Gravitas? How satisfactory do you think the interface (what you see on the computer screen) is?

P1. It's easy to get familiar with, and is useful in understanding what's happening. I find it nice.

P2. Very easy to learn and operate.

How satisfied are you with how you used the simulation?

P1. Although not 100% right from the beginning tasks were completed successfully.

P2. I should have got the bit about total momentum of the system straight away. Still the system was easy to manipulate, so the task did not take too long.

Do you think that working with Gravitas helps to understand better gravitational forces and motion in space? Explain.

P1. I think that trying to succeed in any specific task will help somebody to reveal what's going on with the physics behind it. E.g. realisation that $M_{\text{earth}} \gg M_{\text{moon}}$ forces somebody to consider that conservation of momentum.

P2. Very useful, it shows immediately what the system will behave like. and the graphics are much more interesting than just working out some arbitrary numbers. With more bodies it can be also be used to model very complicated systems.

P4. Useful to check theory by seeing if the answers are correct.

T: Samples Interaction Transcripts**P1: Ben**

R. Here's some instructions and all the features (e.g. masses) of the bodies you will need to put in space.

P2. Right, can I put it anywhere I want on the screen?

R. Yes.

P2. Do I have to give values to all the attributes of the Massobs for them to appear on the screen?

R. Before starting the system what do you think will happen when you start it?

P2. The earth will move towards the moon and the moon will move towards the earth.

R. You can increase the step if you want because it's very slow.

P2. It doesn't like 1000, let's try 500...The moon is moving towards the earth.

R. Why is the moon moving much more towards the earth relatively to how much the earth is moving towards the moon?

P2. They both move towards centre of mass of the system.

R. We can move on. The next thing is to find a combination of velocities to make the moon orbit around the earth.

P2. OK.

R. You can do it either by calculating first and then using your results in the simulation or even if you find difficulties by trying values which you think will give you the result you want (trial and error).

P2. Each of the masses will have an x and a y velocity.

R. Can you explain what you did?

P2. We work out the force of the gravitational attraction between the two bodies. Big m is the mass of the earth and small m is the mass of the

moon. The moon travelling in an orbit experiences a centrifugal force which is given by mv^2/r . So first step is $mv^2/r = GMm/r^2$. The m s on each side cancel out, one of the R s cancels out. Then we rearrange it in terms of v and putting in the numbers we have... And then I will use the values I found for the simulation. and we will see what happens.

R. Just one thing. If you are given a number which is the distance between the moon and the earth, doesn't the value of the masses' radius influence this number?

P2. If the distance is the on between the centres then it doesn't matter. The moon and the earth are taken as points.

R. Right.

P2. Will it orbit clockwise or anti-clockwise.

R. You decide, you are the creator. It's your system.

P2. Right, let's try

R. You can increase again the step 900.

P2. Well if it works it should be slightly unrepresentative of the real system.

R. Why?

P2. This should be circular, while the real orbit is elliptical.

R. So you think that a system which consists just of the moon and the earth, as an autonomous system, can it give any clues about what would happen in real space?

P2. Yes, it could but this velocity we've put in... you could say though that with a slightly slower or faster velocity, it would go into an elliptical orbit, which would be a truer representation of the actual system. and since the other planets' effect would be minimal, e.g. the sun, because... This should be circular, while the real orbit is elliptical.

R. So you think that a system which consists just of the moon and the earth, as an autonomous system, can it give any clues about what would happen in real space?

P2. Yes, it could but this velocity we've put in... you could say though that with a slightly slower or faster velocity, it would go into an elliptical orbit, which would be a truer representation of the actual system. and since the other planets' effect would be minimal, e.g. the sun, because the earth obviously orbits around the sun as well. It depends to what level you want to set up the system.

Comment. It can give you clue but it's not like the real system because the effect of the other planets is minimal.

R. So what will happen now?

P2. Well. It comes around and matches up with this initial point... Oh, the earth is moving.

R. Yeah? Let's wait for a while till it does a full circle.

The earth is moving... I always thought the...

R. Why?

P2. The centre of the mass of the earth is within the volume of the earth so the earth actually will move around.

R. Right, so the earth is moving downwards.

P2. Wow.

R. What else?

P2. The system moves together, doesn't it?... Of course, now I see. I gave the moon a momentum but I didn't give the earth a momentum at all. So the system moves down wards.

R. Which means?

P2. ...

R. Which principle do we need?

P2. We have to go back to the principle of conservation of momentum. The whole system has a downwards procession.

R. and this is because of what?

P2. It is because of the velocity of the earth.

R. which is how much?

P2. Well, initially it was zero. Since we want to stay on the screen we gave a downward momentum to the moon, we need to give the earth an upward one, but since the earth is much heavier...

R. how much will the initial momentum be?

P2. If you want it to be still the total initial momentum has to be zero.

R. How shall we correct this?

P2. Just give the earth a corresponding momentum.

R. Yes. how much?

P2. 12.27

R. So?

P2. If we want the system to remain in the same place we need to give the earth this velocity. Reset.

R. OK. When you created the system you put the earth and the moon in a horizontal line. Why did you do that? Was it accidental or was there any specific reason?

P2. It was not simply to make the system easier. You could always put them in a 45° angle. But then you would have to put x position and y position. You could always put them in a vertical line.

R. So you decided to eliminate either the ex or the y components?

P2. kKeep it down to one either x or y.

R. The earth is slightly moving again. but you could say that it actually gyrates on the spot. They both move around the centre of the mass.

P2. How did you calculate the velocity of the earth. i just equated the momentums. i also made sure that the earth's velocity is in the opposite direction.

R. you said that the momentum of the earth is equal to the momentum of the moon?

P2. well actually equal and opposite.

R. Ah, you took this into account?

P2. Yes.

P2: Brenda

P3. When you told me what the distance is between the moon and the earth I said what? What E8? What is that?

R. It's in exponential form.

P3. So that's the way to enter it.

R. Yes. It will appear on your screen once you put all the attributes.

P3. What about the velocities?

R. You can forget now about the velocities, but you must put in the radius and the mass. Also where you want it to appear on the screen.

P3. If I want it to appear....

R. You must define the x and y position

P3. I suppose I can have a geocentric system.

R. It's on your screen now.

P3. I have to make a decision where to put the moon. If I have axes like that it will be x distance and it will be zero for y.

R. Why did you make this decision?

P3. Just because it saves typing.

R. They are both on the screen now.

P3. Yes.

R. And the next thing we will do is start the system. But before tell me what do you think will happen when we start the system?

P3.... If the system has gravity built in the moon will go straight into the earth. Can I try that? Start.

R. Let's increase the step because it's really small now. It's moving ...

P3. It went straight through the earth. It wouldn't do that, would it?

R. In fact it's the first time I see that. Till now it was a plastic collision where they were moving as one body. What happened there it's gone through,

P3. Well, it appears to pass through but now...

R. Is it coming back?

P3. No, it went through but it's given the earth some momentum and the earth is going the opposite direction. It doesn't seem very likely. Because apart from anything else the earth would break up, wouldn't it?...Right.

R. The next task is to find a combination of x and y velocities so the moon orbits around the earth.

R. One obvious way of doing it is trial and error, but...

P3. We will see. I have real figures for everything, so I need something real for the velocity. Wait a minute... Should my velocity be in m/sec... Well... The very interesting thing... The orbit is all right but the earth is processing.

R. Can you explain what you did?

P3. What I am trying to do is a question of getting things in the right direction... I used the conservation of linear momentum taking the velocity that I had for the moon and I calculated a velocity for the earth and then split in x and y components in about the same proportion I split the other one, the moon and look at that... Not bad. And just actually put them in the opposite direction so when I got positive y and

negative x for the moon, I put it the other way for the earth. That's a thing I was not really sure about... It's all right. Except though it looks as a circular orbit, the earth is not the centre of it.

R. Sometimes a slight rounding of the numbers make a lot of difference.

P3. I used things that I know about the real system and then did some calculations to put in there on the assumption that the other behaviour that I could not influence, was also based on a real system. i think that I was believing that I was given a program in which if I built a system using the real data about the mass and so on. Because the gravitational things or whatever are is for real. I then modified the system by using something else about the real system. And it's now roughly what the moon does, but the real system does not have a circular orbit, does it? I am not sure how...

R. Yes.

P3. In that sense I think I believe that whatever someone put in there, the gravitational aspects did actually reflect the real system. the real behaviour.

R. Where any things you found difficult or confusing: interface (controls, buttons, layout on the screen).

P3. I don't think so. You probably have only left and right hand options for the buttons, because it gives you the best way to work. I don't think it was confusing. The typefaces though would be better if something else was used. These ones look very computer instead of being friendly...

R. Formal.

P3. It looks like a bubble-jet printer outcome. It should be the same as this but more legible. How effective Gravitas was? You were competent users, but would it be equally useful for novices. It is almost too complicated a system in getting people to understand concepts like linear momentum. at what point do people start to learn about circular

motion and angular momentum and I can't help feeling that thing could start things interfere terribly. I can't even visualise what sort of equations...But it's interesting you can sort something out, by using something like a simple principle. I don't know how it would feel if I tried to solve the problem by using trial and error. the first thing that seems to be important is getting the idea of getting the velocity of two components and sorting what this means. for instance I started with my system sitting on the x axis. In the end so much of this comes out as a sort of feeling for mathematical representations. And you get the satisfaction after the calculation of seeing your numbers working. and I wouldn't see it otherwise. What do I get out of it? I have two options either to fiddle or to think it through and see... But these mathematical representations with the simulation became meaningful because the students could get visual images.

Multimedia Motion

P7: Gabriel, P8: John and P9: Steve

P7. That gap there.

P8. You are right.

P7. That's where the collision took place.

P8. That one says delete.

P8. Don't go delete happy.

P7. It seems to speed up there. That one there is a lot bigger.

P8. That will do.

P7. Go to the end. When you've done that press enter.

[Read the text from the text facility].

P7. What did the thing hit.

P8. These are almost constant around one point.

P9. Yes.

P7. We should be accelerating if it is a constant.

P8. Calculation of how well... the collision.

P9. It's that point there where it hits. Click there, it says there 0.8, drag it back to 0.4. O.K... Have a look at the graph.

P8. We've lost it now.

P9. It would have been a nice graph... It shouldn't lose anything.

P8. No it shouldn't.

P7. Go to the data bit. I suppose we'll have to use a calculator.

P8. Oh, no.

P9. Unless we can find the computer calculator.

P8. But we may lose all the data.

P7. Right, it's up to .32 and velocity is...

[They calculate average velocity].

Appendix 2, Gravitas, Multimedia Motion-pilot

P7. Oh look you can highlight the figures, it's like a marker... Multiply by the mass... Air Track collision.

[The go to the text facility and read the text].

P7. I don't think the air track collision is going to be the one.

P9. You're going to be looking at the inner elastic one.

P8. Just do an air track one.

P9. If we have time let's look at the air track sequence.

P7. What happened?

P8. Do you want to get the velocity for before and after.

P7. We'll have to do them separately as the green one keeps moving afterwards.

P8. No, wait.

P9. If we haven't got the masses, how are we going to do that?

P7. If you know that it's probably travelling at a constant velocity, you can probably do the blue one now.

P8. From here.

P7. Yeah, but I know it won't make a nice graph... Can you get one more?

P8. Coming into action now.

[Calculate velocity averages before and after].

P7. We could just take the first and the last and divide it by two... It would be less time consuming.

P8. It looks like it should be there, shouldn't it?

P9. Divide by 8.

P7. So put that down as that being the final momentum of the large mass.

P8. This is the small mass now.

P7. Take that and multiply by 10.

P8. It's a shame we don't have any paper. It would be easier to print out the data.

P9. Masses are... for the first momentum

P7. The other one hasn't got any momentum.

P8. Final momentum.

P9. Is that right.

P8. Is that final velocity.

P7. We didn't have enough points on that blue one there.

P2. It doesn't look good.

P7. What's the difference in momentum?... Add up all the momentums

P9. 0.78.

P8. So what's the data again?

P9. I think that the blue one has been going at the back. 4min/sec.

Q2: Answers to the post test questionnaire

Do you think that working with Multimedia Motion helps to understand better conservation laws and collisions? (Yes/No). If yes can you say how?

P6. No, It was difficult to see how the sequence corresponded to the graph, mainly with acceleration which changed so erratically on the graph.

P7. Yes, it was not very clear to see what was happening on the video screen.

P8. It was useful but not as clear as an experiment in the lab. Seeing something for yourself in real life makes you to believe it more.

P9. It's a bit like working in the lab. The system just applies physical laws.

Appendix 3

ColaCollision (CoC)

Q1: Answers to the pre test questionnaire..... 1

W: Using the simulation..... 7

Q2: answers to the post test questionnaire..... 9

T: Samples Interaction Transcripts..... 13

 P10, P11: Vanessa and Derek..... 13

 P12, P13: Harry and Mick 18

 P14, P15: Elisa and Sara..... 25

Participants

| | | | |
|------------|---------|------------|-------|
| P10 | Vanessa | P11 | Derek |
| P12 | Harry | P13 | Mick |
| P14 | Elisa | P15 | Sara |
| P16 | Pete | P17 | Janet |

Q1: Answers to the pre test questionnaire

Have you got any previous experience with computers (e.g. for word-processing)? (yes/no). If yes give some examples of your experience.

P11. Word processing, spreadsheets, programming of basic and FORTRAN.

P10. Yes.

P12. Programming in C.

P13. Yes, programming, evaluation.

P14. Programming, wordprocessing, Macs, Windows, SPSS (data analysis programs).

P15. PCs, Word, Excel, Powerpoint, SPSS etc.

P16. Familiar with Microsoft Office (Word processing, database, Spreadsheet).

P17. Using Wordprocessing, spreadsheets, CD-ROMs, educational packages, simulations.

What sort of science courses have you done?

P11. A level Biology, Physics and Chemistry.

P10. O level Chemistry with physics, biology, Maths. A level Physics chemistry, pure maths, applied maths.

P12. Maths, physics, chemistry.

P13. O level physics, Chemistry , Biology, Psychology..

P14. O level Biology, O level Chemistry, A level Biology.

P15. Have a degree in chemistry.

P16. Physics to PhD, Chemistry to A level.

P17. Chemistry, Physics to A level, Biology beyond A level.

Have you ever used a computer simulation?

Yes/no

If yes, explain and say what you think a computer simulation is.

P10. Yes. A computer programme which allows the simulation of some reality which you can play with to see how things behave or to allow you to make observations/measurements of a simulated system that you couldn't do for real.

P11. Yes. Something that simulates a real situation or abstract process.

P12. Use of some rules to model the behaviour of something.

P13. Yes, I don't know.

P14. Yes. A computer simulation is a program that simulates a system. The system could be a model, e.g. a model of evolutionary theory (natural selection) or a model of a physical phenomenon such as a weather system. The important thing is that the model involves interactivity variables (or factors) and the program would allow the user (usually) to specify the values of the variables (of the system) and view subsequent changes or relevant outcomes (or change) in the system.

P15. Yes, it is a model of which you run generally in a computer imitating a real phenomenon like behaviour of a pendulum, running of a nuclear plant.

P16. A model of the behaviour of a system, which typically allows users to explore the significant parameters and see how the system behaves, The system could represent a real physical system or something that does not exist in nature.

P17. Something which models a process and has parameters which the user can change in order to see what effect this has on the process.

Can you say what is meant by a conservation law? Can you give any further examples of conservation laws?

P10. B. Within a closed system some entity is conserved no matter what happens within the system. Conservation of energy.

A. Within a closed system some entity is conserved. Conservation of energy.

P11. B. A conservation law expresses conservation of a quantity. Newton's third law. First law of thermodynamics.

A. Conservation of a quantity. Momentum and energy.

P12. B. Some quantity is always equal to some value, regardless of how other things change. Energy, angular momentum are conserved in closed systems.

A. Some quantity is always conserved. Energy, angular momentum are conserved in closed systems.

P13. B. Conservation of something.

A. Some quantity is always equal to some value. Conservation of momentum.

P14. B. Conservation of heat, Conservation of energy, equilibrium.

A. Energy is conserved after the collision of two objects. But I don't know what is meant by a conservation law apart from that it has got something to do with energy being conserved. I am not clear about the difference between momentum and energy.

P15. B. Some qualities are conserved like energy before and after a collision.

A. In dynamic systems energy and momentum are conserved.

P16. B. Conservation of energy, Conservation of momentum, Conservation of parity.

A.

P17. B. Can't really remember, probably to do with energy not being lost or gained, only changing form.

A. Conservation of momentum, masses bouncing off each other.

Now try these questions about collision:

If you have two equal masses moving at the same speed and colliding what will happen after the collision?

P10. B. It depends on direction of motion.

A. They will move apart at the same speed.

P11. B. Are they approaching speed on? They move apart at same speed.

A. They move apart at same speed.

P12. B. They will move in opposite directions, same speed.

A. Will move in opposite directions, same speed.

P13. B. Depends.

A. They go in opposite directions at same speed.

P14. B. I don't know, wouldn't it depend on the type of mass?

A. The momentum of the objects will be the same after they have collided. Momentum before the collision = momentum after the collision. Momentum is a measure of velocity (speed) and mass.

P15. B. They will move like below (at opposite directions) at equal speeds.

A. They will move away at the same speed.

P16. B. Go in opposite directions.

A. Rebound at the same speed.

P17.B. They will both recoil at the same speed.

A. Move away, same speed.

If a small mass collides with a much bigger immobile mass what will happen after the collision?

P10. B. Small mass will have its direction of motion reversed and its speed reduced slightly. The collision is reasonably elastic. Large mass may start to move slowly.

A. Small mass will have its direction reversed. Large mass may move slowly.

P11. B. Assume small mass not accelerating. Is small mass elastic, rigid? Mass moves at same velocity (say v_3), so $m_1v_1+m_2v_2=m_1v_3+m_2v_3$.

A. Small mass will move in the opposite direction, large mass may move as well.

P12. B. The small mass will move in opposite direction with less velocity, large mass will also move.

A. Large mass will move. The small mass will move to the opposite direction,

P13. B. Small mass will stop.

A. Small mass will bounce off large mass which may also move.

P14. B. The small mass will go the other way after collision.

A. It depends on the velocity (speed) that the small mass was travelling.

P15. B. Small mass will move backwards and the big one may move opposite depending on its mass.

A. Small mass will move away from the big one, a little slower than before.

P16. B. The big mass will remain immobile while the small mass will move in the opposite direction.

A. If the bigger mass is really immobile (cannot be moved), then the small mass will rebound off it with the same speed. But if you mean "stationary", initial speed = 0 then the bigger mass will move slowly.

P17. B. They will both recoil, the small one faster.

A. Depends on size of large mass, large one, probably moves slowly (to the right), small one moves to the left fast.

If a big mass collides with a small immobile mass what will happen after the collision?

P10. B. Small mass will move away in direction of motion of big mass. Big mass will probably continue in same direction but in reduced speed.

A. Small mass will move in direction of motion of big mass. Big mass will continue in same direction but in reduced speed.

P11. B. As above.

A. They will both move in the same direction, the small one faster.

P12. B. The big one will stop and transfer all its energy to the small one.

A. They will move together in the same direction.

P13. B. They will move in opposite directions.

A. The big one will stop.

P14. B. They will both keep moving after the collision to the right.

A. It depends on velocity and speed of masses that collide.

P15. B. They might continue moving together.

A. They will move at the same direction together, maybe a little slower.

P16. B. The small one will remain immobile, while the big one will move back in the other direction.

A. Again this question is ambiguous, does immobile mean cannot be moved, or stationary. If (cannot be moved) then the small mass will not move, and the bigger mass will rebound with its speed unchanged (but velocity reversed).

P17. B. They both move to the right, (if the big mass is big enough), the smaller one faster.

A. Both move (to the right) small one faster.

W: Using the simulation

Plan and carry out an experiment which could show in ColaCollision the conservation of momentum. Carry out this experiment using ColaCollision.

P12. Try different combinations of speeds and masses and if the rule holds true, then our confidence in it will increase as the number of tests increases.

If you want to send the boxes travelling away from each other at the same speed, what initial conditions are needed: what masses of boxes/pucks must we use, what initial speed (if any must the boxes/pucks have?

P10. If masses equal initial speeds equal.

P11. If masses equal initial speeds should be equal. If masses unequal initial speeds should be different inversely proportional to the difference of masses.

P12. Masses equal, same initial speeds.

If you want to make one box stop after impact what initial conditions are needed: what masses of boxes/pucks must we use, what initial speed (if any must the boxes/pucks have?

P10. $m_1u_1 + m_2u_2 = m_1v_1 + m_2v_2$

$m_1(u_1 - v_1) = m_1v_2, v_2 = 0$

$u_1 - v_1 = (m_2/m_1)u_2$

P11. Puck means its final speed is zero. i.e. $v_2 = 0$.

$m_1(u_1 - v_1) = m_2u_2$.

If masses are equal difference between initial and final velocities first mass equals initial velocity of second mass.

P12. Equal masses, one mass at rest, the other at any speed.

Q2: answers to the post test questionnaire

What do you think of ColaCollision? How satisfactory do you think the interface (what you see on the computer screen) is?

P11. ColaCollision too slow to respond.

P10. ColaCollision is slow to respond so doing an experiment or playing with it takes too long.

P12. Dull and boring.

P13. Very good idea, pity about reliability.

P14. Poor interface. Slow.

P15. It was not very easy to use. Mass values are not numerical. This could be useful. Did not use graph too much. It would be better if the user could customise the screen and make choices

P16. Far too slow. The interface was OK, when it was set up initially but the system slowed so much that I wasn't sure what conditions I was using. I'd preferred an

P17. Nice and clear visually, too slow to respond and selective about when it responds.

If you were repeating the experiments now, would you change anything in the way you carried them out.

P10. No.

P11. No.

P12. Put units in (of mass and speed)

P14. I would actually. I would write a running record of the attempts, e.g. for each "start motion" note down the masses set and the speeds set and the outcomes of each trial.

P15. Would make a list of v , m to each before and after the collision and try more.

P16. Be more systematic in recording the conditions and results.

P17. I'd like to do them again by myself, don't like working in pairs, cannot concentrate and then get fed up.

How satisfied are you with how you used the simulation?

P10. Very but couldn't do things I wanted to do because the scales were not likely enough divided.

P11. OK. Rather helped.

P12. Pretty much, but it seems to also need knowledge of conservation of kinetic energy to work out questions.

P14. Not very satisfied. See question directly above.

P15. Not very effectively but it wasn't very quick.

P16. Not very.

P17. No.

What do you feel you have learnt after using the simulation?

P10. That DM^3 is a problem on the Power PC.

P11. That my understanding of momentum is incomplete.

P12. Something about the problems of limited memory on computer use. Not much else.

P13. A bit about conservation of momentum. Nice to see the interface of DM^3 .

P14. That after collision objects will behave in different ways depending on their mass, the other object's mass and the speed they are travelling.

P15. That I don't know about the interaction of m and v in momentum and how they affect the behaviour of the masses.

P16. I was confused by the behaviour of the system when we were trying to make the boxes travel away from each other at the same speed.

P17. Not much.

Do you think that working with ColaCollision helps to understand better conservation laws and collisions? Yes/No

If yes can you say how?

P10. Because it was easier to see and measure what was happening. Measuring changes in velocities to calculate is not easy in real life.

P11. Made me appreciate that after collisions objects may not only move apart but may move in the same direction or one may remain stationary.

P12. Not significantly. Could be much better in 2-D with conservation of energy where it can seem more surprising with collisions at arbitrary angles.

P13. Yes, it gives a nice, broad overview.

P14. Yes, specifically collisions. still not sure what a conservation law is. Trying out different things and seeing the consequences.

P15. It may help but we did not spend enough time. Users can be given problems to solve and they can be required to give numerical answers. Maybe more specific answers.

P16. No. The data on the screen were less detailed than other simulations i.e. the mass size, small big and large, do not permit easy calculations to be made with accuracy.

P17. I think I would if I were working through by myself. Seeing the processes is something that is very difficult to do in real life. Some of it naturally makes sense in my mind, but only up to a point; beyond that I lose my grip on why it naturally made sense! Having the visual input allows me to think around it without getting lost but I would need to work on it alone to get maximum benefit.

How does the system calculate the figures?

P11. It uses the physical laws.

Do you think that the system helps to understand a real system?

P12. Yes, because it was easier to see what was happening. Measuring changes in velocity to calculate is not easy in real life.

T: Samples Interaction Transcripts**P10, P11: Vanessa and Derek**

P11. Momentum is mass times velocity.

P10. Did you know what an experiment would be to demonstrate...

P11. No.

P10. The invention of frictionless systems had not happened when I was at school. I've used them since, but the air tracks are frictionless so you can collide things and measure velocity.

P11. Right.

P10. So we've got to... It actually changes. While these ones are the same size. And this is twice... Which one do you want us to play with? Start with the same ones or?

P11. Actually I'd like to see something happening first.

P10. More or less? Start graph and start motion... O.K. So we've got actually very small momentum on one side... Right.

P11. That's interesting.

P10. I'm not sure it's doing what I actually asked it to do.

P11. Are you trying to stop to graph?

P10. I was trying to... It hasn't. It still... It did now... That's the collision.

P11. In the graph, this is the time axis, but is that momentum or velocity?

P10. I don't know what it is?

P11. This must be the small one (points at graph), because it changed direction. It went above the dotted line.

P10. It was also the one we chose as having the lower velocity (points at graph). Somewhere it came up to say that it was 20, so that would do

finely with velocity and momentum. So positive direction is the one going this way (right). One way to find out is by having different masses and the same speed. Those look like. We had 40 and 20m and that looks like twice that. We also had different masses. so that would be very much more 40X20 and this would be 20 x1. so these must be velocities... It's a measure of velocity. So...

P11. So if we repeated with different masses but same initial velocities.

P10. We need to start the graph.

P11. Now there are labels at the graphs saying speed and time.

P10. Now we know that the graph is... What we cannot do is have our masses make them collide and it would appear to give us the measures.

P11. For both objects we can demonstrate, we can go through our three masses for one object, and about speed... And show with the speeds we came up through that we have conservation. This is a clue..

P10. Then we can actually do an experiment in which we can vary the masses.

P11. Right.

P10. Keep the speed...

P11. Before and after the collision... It's the same... Right mass and its velocity, left mass, and velocity. It says...

P10. We could use a 100 for the velocity before and... Simple figures to make things easy.

P11. Keep the same velocity. And just change the mass.

P10. That's right. If we've got in terms of momentum units, we will have sort of 100, 100+200, 100+2000.

P11. What we can do is measure the after the collision velocities and we can begin with...

P10. We'll still have to multiply them by the masses and then add them. You know if we add these together, will they be the same?

P11. Both speeds 100.

P10. It wouldn't let me change the speed controls until we reset the whole thing. Waiting until you believe you've actually carried out the thing and that finger pointing says you have done it, and it will start with... 1, 1, and 100. start graph and start motion.

P10. the speed controls have gone back to...

P11. Reset. Stop the graph. Clear graph. Try again the speed controls.

P10. O.K. That looks set. So we get the speed afterwards which is -100 and 100 again. O.K. Do this side, the one with the mass changes the speed starts positive.

P10. It responds in the end but it's taking its time.

P11. Medium mass. Here we go... Same velocities 100.

P10. right.

P11. 66.6666...

P10. The larger mass has the -33.33333... This one which is the 2m. it's 66.666...

P11. It's like I have the minus and the pluses the wrong way around.

P10. We had m and 100 and m and 100. After m and 100 and m and 100. And then 2m and +100 and m and -100. after 2m and -33.33 and +m and +66.66. that's interesting. Hang on. right... Great it works.

P10. I'm asking it to stop the graph and it won't. i wonder if I have to wait each time till it carries out each command... Big mass... We will have 20 m. can we predict what the velocity will be. Off we go... That's interesting, now they are going in the same direction. The speed is 80.9 big one) and... I cannot quite see.

P11. 80.9 for the big one. And 280.7. 20X80.9+...

P10. Afterwards we have 20 times and..

P11. I thought you said 280.7.

P10. Yeah. That was the first one.

P11. And 80.9.

P10. $20 \times 100 - 100 = 280.7 + 80.9 \times 20$. Yeah, 1900.

P11. I got a decimal point.

P10. I did round it. 81. Would we want to do it by keeping the masses the same and varying the speeds?... You don't think it's necessary...

P11. No.

P10. That's fair enough.

Task 2.

P10. the boxes got to have the same mass and travelling at the same speed. And if they have different masses, they will be travelling at different speeds, appropriate ratios.

P11. Yes, yes... If masses are equal, initial speeds equal. if masses are different and...

P10. Specific conditions, if things are... we cannot set whatever conditions we want, can we? Can we do it the other way around. One velocity zero to start with... We cannot assume we will reverse these conditions... It's more easy to envisage the momentum transfer so such one is stationary, the other one moving. Momentum is transferred and it's only one that moves afterwards. But if you got... If they are both moving and you want one to stop... like in snooker... No, that's not straight forward because you have to take into account things like spin, to make it stop. There's something you can make the one under the impact stop, but it has to do with reverse spin... It has to do with the way you actually hit the ball.

P11. Yes.

P10. One velocity is equal to zero...

P11. v_2 is zero, that's the far left one, and m_2 ...

P10. If the masses are equal. The velocities... the initial velocity of one minus the other must be equal to the final velocity of the other.

P11. If the masses are equal the difference between the initial and final velocity of the first one must equal the initial velocity of the second one.

P10. I was just wondering if this is not some kind of extreme case. If the masses are equal it means that then...

P11. If the masses are equal, one must be slow.

P10. This means this has to be very small...

P11. no, this difference whatever it is... final and initial between those two, it's the same as the initial velocity of the other one.

P10. Yeah, O.K.

P11. If masses are different you have to change that proportion.

P10. Can we show that? You believe the mathematics... We can say if we've got masses travelling at a certain velocity to start with. Let's take 20m/s and it will collide with a mass of... we can work out what velocity this will be...

P10. I think we will have to make the one on the right to stop. We cannot really put, that's the difference. I am going to try that... It didn't work... The only way you can... If it's travelling very slowly, it may be able to stop it.

P11. Let's try with the big mass...

P10. It has a lot of momentum. We want it to lose all its momentum and stop. how do we arrange this exchange? If they have the same momentum, but one more comes from its mass than its speed...

P11. It has to be zero.

P10. Well, if it's very massive and it stops. If they both move... I will try that one very slow, as slow as we can make it (big mass) and that one as fast as we can make it. That's 20 times 20. I will run my

experiment... that's not far off. it nearly stopped. It didn't quite stop... I had 20, the minimum you can go with the big mass and 100, the maximum you can get with the small mass.

P12, P13: Harry and Mick

P13. Conservation of momentum is two bodies...

P12. The total momentum is the sum of the momentum of the individual bodies. It's constant, before they collide and after they collide.

P13. So conservation of momentum applies in principle to bodies in interaction or collision?

P12. Individual momentum can change but the total doesn't.

P13. OK. What would prove it then?

P12. You cannot prove it.

P13. We will use the small mass and... speed. How do you run it?

P12. I don't know.

P13. I have no idea about how to start this thing so...

P12. Suspended operation.

P13. Speed for the left and speed for the right and the two small masses.

P12. Stop the graph.

P13. They were both travelling at the same speed and they collide. and then there is a massive reversal of velocity. And now they are both travelling at constant speed.

P12. Yeah.

P13. Where is the momentum then?

P12. The masses are both the same and since they are travelling in opposite directions, the total is the difference. And the difference is clearly the same before and after.

P13. Sometimes the velocities are the same. I don't know what happens if you change them... So if the velocity is the same the momentum is conserved.

P12. Yeah.

P13. But the question was how to prove...

P12. If you change the speed and the mass is the same, and similarly if you go to the medium mass and the big mass, which implies that momentum is conserved.

P13. Right. Consistent. But we are not getting any output for the momentum. We don't actually graph momentum here.

P12. But this is mass in gr.

P13. So because the graph has no scale it actually shows velocity and momentum. What else does it show?

P12. It shows speed.

P13. Let's use the big mass . O.K.?... Let's keep the mass constant and change the velocities. Right?

P12. Yeah.

P13. We should keep the speed the same. Eh?... So keep the speed first of all (with the big mass), and shifting the masses... There's probably a programming error, it does not respond... It's not robust enough.

P12. Is it black and white?

P13. I think so.

P12. What age group is it targeted to?

R. A level, year 12 or first year University students.

P13. Full speed? And big mass?... I think there is a problem. When you start motion you get time passing.

P12. And the graph starts before you start motion.

P13. That's interesting.

P12. The big mass is 20 times the small one, in which case you would expect the height of this to be 20 times the height of that in the graph.

P13. So they are both going off the screen at a certain speed, same direction. The large block in the left doesn't change its momentum.

P12. It slows down a bit.

P13. But the small block went off at the same rate. 80m/sec.

P12. We need a calculator to prove it. The big mass is 20 times the small mass, if the small is m . So that's the momentum initially. Momentum before.

P13. Let me see. Mass times velocity. You have two bits here, each mass times velocity.

P12. That's the big one going 100, that's the small one going 100 in the opposite direction. That should be... It does work actually. That's the speed of the small mass...

P13. Hmm...

P12. The same as before.

P13. We have got a proof. And we have a proof by working out the sum from the formula.

P13. Let's see the question again. Design an experiment which shows the conservation of momentum. We assume that we know what momentum is... One of us already knew what the conservation of momentum was so why play around with the idea of finding a way to show the conservation of momentum?... using this package to learn if you didn't know what the conservation of momentum was.

R. The simulation does not test people's knowledge but how they can apply their theoretical knowledge to physical situations, once they are familiar with the concepts.

Second task

P13. Check the velocities of the same mass? Actually do these speed controls set the actual speed of the mass or set the push forces? Are they speed controls?

P12. Well, we want them to travel away at the same speed. The masses are equal, what happens is that the speeds reverse.

P13. So it's two conditions: same initial speed... If the masses are the same and the initial speeds are the same, then the post collision speeds will be the same.

P12. But there are probably other cases when the conditions are different. If one mass is twice the second one.

P13. It will be half the speed then. If the larger mass is twice the smaller mass, if the larger mass is travelling at half the speed, then the post collision speeds will be the same.

P12. Let's try it out.

P13. Medium mass which is twice the speed of the small one.

P12. What speeds they have when they collide. Needs a second condition.

P13. So we have a conservation of energy assumption as well.

P12. Yeah, because the energy is conserved. And it's square of the speed, so it doesn't matter what direction they will go.

P13. Well, let's try these cases out. If we try half the speed on the left... Nothing is happening. Momentum will be conserved if they take off after the collision at twice the speed. This is coming at half the speed and they collide. If they both at the same speed. There must be the same amount of momentum in both directions... Do we want them to go with the same momentum or the same speed?

P12. Same speed.

P13. In this case there is no momentum at all. Because they move at twice the mass and half the speed. So when they collide, they will stop. Or... they could just stop or move away at the same... No...

P12. They won't stop. Actually that's not true. Momentum still has to be equal and still has to cancel out. So.. they will still move off at half the speed in opposite directions.

P13. Is the problem that you cannot just talk about units of speed.

P12. The speed just cancels out in this case... The general case would be each to change direction.

P13. And then they disappear off at the same speed.

P12. They wouldn't go off at the same speed. They would go off at their individual speeds. momentum afterwards has to cancel out. Total has to be zero.

P13. Let's try it out. Left is 40, right is 80. Medium and small. and after the collision the speeds will be the same. So they change direction but not speed... So we have one condition where the masses and the speed are the same. second condition where we have different masses.

P12. all we know in this case is the total momentum is zero. So it has to be zero after the collision.

P13. Seems in that case the mass was irrelevant. What was important was the speed. The speed remains the same, irrespective of the mass. so if we want the smaller one to slow down. May be we should try it out. Equal speeds. The smaller one would have gone away and it wouldn't travel more slowly than it arrived. It would have been accelerated by the heavier block. They both hit each other with the same impact. With the same momentum...If the small block hits the large block and they are both travelling at the same speed, the heavy block would carry on in the same direction.

P12. It's not just the speed that is important. It's the momentum.

P13. Right.

P12. So we can state just one initial condition. The masses are equal.

P13. so the left one is twice as big as the right one, And the right one... But the right one is not twice as fast. Just 10 more... And... That's interesting. See that? The initial speed is 60. In the first place when it was doubled, the post collision speed was exactly the same as... Now we've split the difference between the speeds and it's only increased by more. The post collision speed of the smaller block is now faster than the pre collision speed.

P12. The small mass has less momentum than the large mass.

P13. Right. What happens then if we increase the speed... mass times velocity plus mass two times two velocity divided some mass... So the momentum of the final speed... you have constant velocity both of the post collision objects, some of the momentum of each of the two objects...

P12. Mass two is two times mass one. That's the medium mass situation. the speed of mass 2 should be equal to half of the speed of mass one. Opposite directions. To make sure when they collide they stop.

P13. Right.

P12. You want them to move away at the same speed, it should be at one and a half times that speed.

P13. We have 40, the large is 40, so you need 100... The post collision speed must be the same.

P12. It doesn't work like that. It's actually gone up. It was 73 before... If you have the large mass at 10 and the small mass at 20?

P13. We have 40 and 80. And they left at the same speeds. We have 40 here for the Medium mass left and 80 on the right. And the left with the same speed in the opposite direction... And then we did 60 and

then the white one moved away at 73. And then 100 and moved away at 90.

P12. Try the smaller mass at 40 (right one) and the larger mass at 10.

Third Task

P13. It's got to have infinite mass.

P12. If you have one of the masses at zero speed and the same mass coming and hitting. The general case again could be tricky. Let's go for the simple case rather than the general one.

P13. Yeah. I don't want to start the graph. Stop the graph... So make then sure. same mass. One's got a zero speed and this will be the right one. But it will stand still after the collision... I think if we got longer and we might do more... If these axes were labelled.

P12. I think the students should have units for mass etc.

P13. This isn't really speed. Is it? It's velocity.

P12. Yes, it is. They could have momentum as well. Well, I think that part of the exercise is to work out momentum.

P13. labelled. There are things about the interaction here. E.g. stop, start Graph when you feel like it. Stop it before you clear it. And it should tell you what the relationship between the masses is. m , $10m$, $20m$.

P12. I don't think that it actually travels with $20m/sec$ across the screen, does it?

P13. I think there is a problem. When you start motion you get time passing.

P12. And the graph starts before you start motion... The big mass is 20 times the small one, in which case you would expect the height of this to be 20 times the height of that in the graph.

P14, P15: Elisa and Sara

P14. I don't know what the conservation of momentum is.

P15. It's simple, you know, energy before collision is equal to energy after collision.

P14. What about the momentum bit?

P15. I don't remember the formula. I think it's mass times velocity... The product of mass and velocity of a body. When two masses collide the total momentum before the collision will be equal to...

P14. Momentum has to do with velocity and mass, weight and speed.

P15. Yeah.

P14. In layman's terms... So momentum is a measure of weight and speed (kind of). Before collision and after. Right?

R. Total momentum before equals total momentum after.

P15. Let's see it.

P14. In the left we will set the speed same as the right.

P15. Let's try medium to see if it works

P14. Shall we put them both at small?

P15. Did you start the motion?... Did you click Reset?

P14. No, I did not touch Reset.

P15. Click Reset.

P14. The speed controls have gone back.

P15. Reset.

P14. Shall I put the speeds back?

P15. Yeah.

P14. And then start... And they've gone... There is a graph in the background then. The time is being measured, speed 1 and speed 2... Speed before and speed after?

R. It doesn't give you speed before and speed after. You have to watch the counter, after the collision.

P15. Let's pause motion.

R. If you want the graph as well you must start it..

P14. 20 and 40. Reset the mass. Happy with 40? It doesn't really matter (for task 1). Start.

P15. They've stopped and they've gone to 0. This must be velocity (on the graphs). They are going in the opposite direction. And below 0 it means it goes backwards.

P14. Right... So do you think that momentum is conserved?

P15. I think that it's something like mass 1 times v_1 initial plus mass 2 times v_2 initial equals the other one mass times v_1 final. Momentum of an object is mass times velocity. You have two objects. We need to show that momentum before the collision... We don't have values for mass on the screen. Do we?

P14. No we don't.

P15. Let's change the velocity.

P14. Reset.

P15. Very difficult program to use.

P14. Shall we clear graph?... Stop graph... Has it crashed? It's not crashed because it's still ticking.

P15. You want to send them away... So, you want final velocities to be equal. If the initial speeds are the same, then it's straightforward.

P14. We know that.

P15. You want this one to stop.

P14. To set it up so that one of them stops.

P15. Yeah, we will try and see.

P14. So do you want us to do the third task?

P15. Yeah, if the masses are equal and the speeds are equal, they will move away from each other at the same speed. This one is like the one we did for the first task. Practically we solved it.

P14. You could balance it up in different ways.

P15. Yeah.

[They read third task].

P14. I think one is big. We can't change this one, only change the other one... I keep forgetting that.

P15. In that condition they might continue moving together.

P15. That's the big one and that's the small one, we set the little one very slow. It would just stop. And that would bounce off.

P15. Let's see what happens.

P14. That doesn't have to be moving. We don't have to set up this moving. Do we? As long as there is some impact.

P15. But it has to stop after impact.

P14. You mean it has to be moving in some way, it doesn't have to be stationary.

P15. It will be moving, but it will stop because it will transfer all its energy.

P14. Well, I think this has to be very slow and that's going to be slow.

P15. Let's keep it at 40.

P14. We don't need the graph now.

P15. No, it wasn't that helpful with the graph, was it?

P14. What's going to happen?

P15. After impact. This one (Right) is fast you see.

P14. It's been knocked by the other one.

P15. I think we should reset it and decrease the speed of the big one...

P14. Yeah. Reset. Give it a little time. I want to keep the little one at 40... Very fast, isn't it? Oh, nearly. Here it goes again.

P15. 14.1m/s... The speed stays constant during the motion... Let's decrease it now only a tiny amount.

P14. Can we do that or is it very crude?

P15. There. And the other one will be 40... I don't think you can do that. It can only be 20, 40, 60... Let's increase the other one at 60 then. Even if it's little it's fast enough to set it moving.

P14. Oh, we've got the right idea.

P15. 80... we can decrease the mass of course.

P14. It's big, isn't it?

P15. Make it medium.

P14. Can't we go to 100.

P15. Yeah, you can.

P14. O.K... You see, put it to 100 then.

P15. You are right.

P14. If 100 doesn't work...

P15. You never know if these things might work.

P14. This is big or medium? Let's put medium... 20 for left, 100 for right... Let's increase the other velocity... let's keep something constant.

P15. I forgot where we were.

P14. We did 100... We want it at 60 and that's 20... oh, Decrease that at 40... The little one is going quite fast... I want that to be big now. I can't work it out

P15. What if they are going at the same speed?

[They vary the ratio of velocities and RUN].

P15. We should be calculating these things... It's like 1/10. Next ratio? We need a lot more difference... It's stopped.

P14. No, it nearly stopped.

P15. I am not good at this kind of thing, you know.

P14. Why, don't we have a really, really big one.

P15. Why don't we have equal masses, move only one, one will be moving, and continue to move... If one is stationary the other is moving, then only one will continue to move. I know by experience, physics...

P14. I still believe we should make this bigger. We tried that. Do what you say. Make the same mass. Same size.

P15. One is 60 (or whatever you like) and the other one is 0.

P14. But the other one is not moving at all. Both are supposed to be moving.

P15. No, it doesn't say.

P14. Make one stationary. O.K. Make one box stop.

P15. We can only do this with equal masses and equal velocities. That's the problem...

P14. You clever thing.

P15. Oh, it's not clever, I know that.

R. How do you know?

P15. Masses are equal, but there is only enough to move one box, and it's moving.

P14. It nicks the energy.

P15. But is it transfer?

R. Is it velocity you are talking about?

P15. I think it is K. E.

P14. Same mass.

R. You ended up using equal masses. What was your logic behind that?

P14. No, I thought that a big one would sort it out.

R. What do you think determines the motion of the masses? What is the rationale for using the big mass.

P14. It might be too heavy in itself to move. But thinking about it, the little one won't stop it.

P15. You should use correct proportions of mass and velocity. You know the energy. You can make a big mass with little velocity to have equal energy to a small mass with big velocity... But the calculations are too much.

P14. We also had problems with the speed controls.

P15. And you also don't have enough choice for the masses.

Appendix 4

Multimedia Motion (MM)

| | |
|--|----|
| Data catalogue | 1 |
| Q1: Answers to the pre test questionnaire..... | 2 |
| I: Using MM..... | 12 |
| Q2: Answers to the post test questionnaire | 19 |
| T: Samples Interaction Transcripts..... | 23 |
| Students S1: Daniel, S2: Robert..... | 23 |
| Students S3: Barry and S4: Judith. | 27 |
| Students S9: Roger and S10: Ray..... | 32 |
| IT: Interview transcripts | 39 |

Participants

| | | | |
|-----|--------|-----|--------|
| S1 | Daniel | S2 | Robert |
| S3 | Barry | S4 | Judith |
| S5 | Nora | S6 | Irene |
| S7 | Duncan | S8 | Jeremy |
| S9 | Roger | S10 | Ray |
| S11 | Agnes | S12 | Simon |

Data catalogue

| Date | School | Students | Type of data |
|---------|----------|----------|-------------------------|
| 7.2.96 | School A | S1 | 1, 2, 3, 4, 5, 6, 7, 8 |
| 7.2.96 | School A | S2 | 1, 2, 3, 4, 5, 6, 7, 8 |
| 9.2.96 | School A | S3 | 1, 2, 3, 4, 5, 6, 7, 8 |
| 9.2.96 | School A | S4 | 1, 2, 3, 4, 5, 6, 7, 8 |
| 12.6.96 | School B | S5 | 1, 2, 3, 4, 5, 6, 7*, 8 |
| 12.6.96 | School B | S6 | 1, 2, 3, 4, 5, 6, 7*, 8 |
| 18.6.96 | School B | S7 | 2, 3, 4, 5, 6, 7*, 8 |
| 18.6.96 | School B | S8 | 2, 3, 4, 5, 6, 7*, 8 |
| 24.6.96 | School C | S9 | 1, 2, 3, 4, 5, 6, 7, 8 |
| 24.6.96 | School C | S10 | 1, 2, 3, 4, 5, 6, 7, 8 |
| 24.6.96 | School C | S11 | 1, 2, 3, 4, 5, 6, 7, 8 |
| 24.6.96 | School C | S12 | 1, 2, 3, 4, 5, 6, 7, 8 |

*poor soundtrack on video

Key to data categories:

| | |
|--|---|
| Observation schedule | 1 |
| Student computer and science questionnaire | 2 |
| Student pre-program questionnaire | 3 |
| Student post-program questionnaire | 4 |
| Student interaction worksheet | 5 |
| Notes | 6 |
| Video tape | 7 |
| Interview audio tape | 8 |

Q1: Answers to the pre test questionnaire

Have you got any previous experience with computers (e.g. for word-processing)? (yes/no). If yes give some examples of your experience.

S1. Word processing, multimedia

S2. Poster, style-word processor, graphic design, spreadsheets

S4. Using school computers

S5. Using word processing, databases spreadsheets etc. in school for tasks involving writing letters, collecting data etc.

S6. Using datalogger to carry out experiments.

S7. Word processing, spreadsheets, databases, programming, games playing, building PC compatible machines at work/image editing, networking.

S8. No

S9. Word-processing, using spreadsheets, databases, e.g. MS-works. Programming in BBC basic and QBasic. Playing games.

S10. I have done previous pieces of school work, at home and at school.

S11. Using Computers to investigate physics problems, word-processing, collecting data, spread-sheets, design work, programming, plot growth over time.

S12. Word processing and record of achievement

What sort of science courses have you done in school?

S1. GCSE Double Science, GGCE A-level Physics Chemistry

S2. GCSE modular science currently A-level physics

S3. GCSE mixed double science physics + chemistry A-level

S4. GCSE modular science.

S5. GCSE dual sciences (Physics, Biology + Chemistry). Am now taking Biology + Physics A-levels.

S6. A level Biology, Chemistry and Physics.

S7. Chemistry and physics GCSE Physics A-level

S8. GCSE physics, chemistry, biology. Now taking A level physics and biology.

S9. Maths, Physics, Chemistry, IT at GCSE. Maths, Physics, Computing at A-level.

S10. GCSE double awards in sciences. Now partaking in A level physics and A level chemistry.

S11. GCSE science double award, GCSE biology

S12. GCSE science

Have you ever used a computer simulation? (Yes/no). If yes, explain and say what you think a computer simulation is.

S1. No.

S2. flying/racing games, also virtual reality games, moving pictorial games viewed by one on screen.

S4. Don't know.

S5. I think a computer simulation is where the computer is used to give you information by means of sound pictures and movement as in a CD-ROM where it is capable of showing short screen items etc.

S6. No.

S7. It is where a computer is used to model everyday events so that different variations in conditions in the simulation can be varied at a low cost.

S8. No.

S9. A computer simulation is a program designed to simulate a part of the life, e.g. moving, finance, etc. Many games are simulations e.g. sports simulations, flight simulations, Sim city (the simulation of building a city). Computer simulations are usually as close to reality as possible, so that you can ask: "what if?" to many situations, and the simulation to show you what should happen.

S10. I think that a computer simulation is a programme designed to make the mind think that you are in the real life situation which the computer is portraying.

S11. No.

S12. I think a computer simulation is either a programme that can record accurate information from an experiment or actually simulate the experiment itself after someone inputting conditions

Can you say what is meant by a conservation law? Can you give any examples of conservation laws?

S1. B. A conservation law is where a quantity is conserved, i.e. the quantity at the start and the end of a process is the same. Conservation of energy, momentum.

A. A conservation law is a statement to say how and where something is saved or conserved and by what means i.e. conservation of energy: energy cannot be created or destroyed it can only be transferred from one form to another.

S2. To conserve is to keep.

S3. Yes , if cow eats grass some energy is transferred to the cow.

S4. You can't gain or lose energy.

S5. B. A conservation law is a statement to say how and where something is saved or conserved and by what means i.e. conservation of energy: energy cannot be created or destroyed it can only be transferred from one form to another.

A. A conservation law tells you about the transfer, conservation and maintenance of energy whether it be a collision or movement, etc. An example of this is the conservation of momentum.

S6. B. Conservation law means that energy cannot be lost or used up, but is changed into different forms e.g. heat, energy.

A. Law of conservation when a body collides with another body its momentum, energy will be equal provided there are no outside influences.

S7. B. The total momentum of objects before a collision is preserved after the collision if there is no friction.

A. The total momentum before a collision is preserved through the collision so that it is the same after the collision e.g. hitting a ball with a bat.

S8. B Conservation law keeps something going e.g. A pass on of energy. Conservation of energy. Conservation of momentum.

A. A conservation law is how an energy (or form of) is passed from something to another without being lost. Conservation of momentum. Conservation of energy.

S9. B. Conservation laws e.g. energy, momentum are when nothing is lost, i.e. no energy is lost when two balls hit each other, for example.

A. Same as before.

S10. B. A conservation law is a law which describes an effect where nothing is lost or gained during a process. Conservation of momentum.

A. A conservation law is a law which can include the transfer of energies of some form from one object to another object. Conservation of linear momentum.

S11. Energy cannot be destroyed only changed to other forms.

S12. Conservation law is the conservation of momentum and energy within and elastic collision e.g. two trolleys travelling in the same direction, one travelling faster than the other, colliding but carrying on in the same direction.

Now try these questions about collisions. If you have two equal masses moving at the same speed and colliding what will happen after the collision?

S1. B. They will move at equal speeds in the opposite direction.

A. They will move at equal speeds in the opposite direction.

S2. B. After the collision the objects will continue to move with the same speed, but their relative directions may change.

A. After the collision the objects will move at equal speeds in opposite direction.

S3. B. Depends on what direction they are moving if both in one dimension and are opposite they will rebound at equal speeds.

A. They will rebound at equal speeds.

S4. B. They will stop.

A. Will move at equal speeds in the opposite direction

S5. B. They will either stop completely or will begin to move back in the opposite direction with perhaps a slower speed.

A. After the collision the two bodies will move back in the opposite direction with the same speed or the two bodies will stop.

S6. B. Inelastic collision, they will remain together and continue moving.

A. They will continue moving at a constant speed.

S7. B. Assuming that it is elastic, the two equal masses will rebound with the same velocity that they collided with in opposite directions.

A. They will move off in opposite directions with equal velocity.

S8. B. They will rebound with the same speed after the collision.

A. They will rebound with the same velocity in opposite directions.

S9. B They will both rebound with the same velocity back in the opposite direction.

A. They will both rebound with equal energy in exactly the opposite direction.

S10. B Both masses will end up stationary.

A. Both masses will end up stationary.

S11. B. Both masses bounce back with same speed.

A. Both masses bounce back with same speed.

S12. B. They will move in exactly the opposite direction as before the collision.

A. Same as before.

If a small mass collides with a much bigger immobile mass what will happen after the collision?

S1. B. The small mass will lose most of its momentum and return at a slower speed in the opposite direction.

A. The small mass will return at a slower speed while the big mass will move in the other direction.

S2. B. The small mass will rebound a lot and the bigger mass will rebound lightly.

A. The small mass will rebound and large mass will move in the opposite direction.

S3. B. Small mass will rebound backwards and the immobile mass will move.

A. It will bounce off it losing some of its speed, through energy passed over to the immobile mass and moving it slightly.

S4. B. If total energy change is completed then the small mass will rebound and the large mass will have a small velocity.

A. If total energy change is completed then the small mass will be stationary and the large mass will have a small velocity.

S5. B. The large mass will stay immobile and the small mass will either stop or travel a tiny distance then stop in the opposite direction.

A. The bigger mass will move slower to the right and the smaller mass will rebound.

S6. B. The small mass will bounce off the large mass which will move in the opposite direction.

A. The kinetic energy will be transferred causing the larger mass to move and the smaller mass to rebound.

S7. B. The large mass will move a little in the direction of the small mass, and the small mass will rebound off the large mass. No energy or momentum is lost, as in the other two above or below.

A. The large mass will move to the right, the small mass will rebound to the left.

S8. B. The small mass will rebound with same speed. Although some energy will have been lost due to friction, heat and sound.

A. The larger mass will move off with a constant speed and the smaller mass will rebound with half (assuming larger mass is double the smaller one) the original speed.

S9. B. The smaller mass would rebound away from the larger mass which may move slightly or not at all (depending on the size of the larger mass).

A. The bigger mass would move off with constant speed whereas the little mass would rebound and move in the opposite direction, but slower than its initial velocity.

S10. B. Both masses will end up stationary.

A. Both masses will end up stationary.

S11. B. Small mass will bounce back with lower speed and large mass will start moving slowly.

A. Same as before.

S12. B. It will bounce off it losing some of its speed through energy passed over to the immobile mass moving it slightly.

A. It will bounce off it losing some of its speed through energy passed over to the immobile mass.

If a big mass collides with a small immobile mass what will happen after the collision?

S1. B. The large mass will lose a little of its momentum but it will still return in the opposite direction still at a reasonable speed.

A. The large mass will lose a little of its momentum but it will still move in the same direction with the small mass.

S2. B. The big mass can give all its kinetic energy to the small mass.

A. The big mass will give some of its kinetic energy to the small mass.

S3. B. It will stop or rebound not as far.

A. The large mass will slow down and the small mass will move off quite fast.

S4. B. If total energy change is completed the big mass will be stationary and the small mass will have a large velocity.

A. If total energy change is completed the big mass will move and the small mass will have a large velocity in the same direction.

S5. B. Both the big mass and the small mass will move in the direction of the big masses' original movement.

A. They will both travel in the direction of the big masses' original movement..

S6. B. The larger mass will remain stuck to the small immobile mass.

A. The smaller mass will move at the same speed as the larger mass which will continue moving.

S7. B. The small mass will be given energy to move in the same direction as the large mass, and the large mass will carry or going in the same direction, too.

A. Both masses will move off to the right, the larger mass losing weight.

S8. B. The larger mass will rebound with the same speed. Losing a small amount of energy.

A. The small mass will move off with a greater speed than the larger mass' original speed. After collision the larger mass will move in the same direction but at a slower speed.

S9. B. The smaller mass would be accelerated in the direction of the travel that the larger mass is previously travelling in.

A. The smaller mass would move off quickly and the larger mass would keep moving but maybe with a slightly slower velocity.

S10. B. The large mass will stop. The smaller mass will move at a speed faster than the initial speed of the larger mass. NB. In all three collisions I have assumed no friction and air resistance and that all three collisions are inelastic.

A. The small mass will move off and the larger mass will move in the same direction. Both masses will change velocity with the following relationship.

$$\Delta v_2 = \Delta v_1 \times m_1 / m_2, \Delta v_1 = \Delta v_2 \times m_2 / m_1.$$

S11. B. The immobile mass will move a little and the other larger mass will lose momentum slightly.

A. The large mass will slow down and the small mass will move in the same direction.

S12. I don't know.

A. The large mass will slow down and the small mass will move off quite fast.

I: Using MM

Air Track Collision 1: Explore the sequence and see if you can measure the velocities of the objects before and after the collision.

S1. $v=1.5\text{ms}^{-1}$

$v=1.4\text{ms}^{-1}$

$m_1=m_2$

S2. Before $v=1.5\text{ ms}^{-1}$

After $v=1.4\text{ ms}^{-1}$

Loss of 0.1ms^{-1} experimental error

S3. 1.5ms^{-1} before collision

$1.3.\text{ms}^{-1}$ after collision

S4. Velocity= 1.5 ms^{-1} for first blue mass before collision

velocity= 0 ms^{-1} for first blue mass after collision

velocity= 0 ms^{-1} for second blue mass before collision

velocity = just under 1.5ms^{-1} , about 1.3ms^{-1} for second blue mass before collision

S5. $v_1=3.085$

$v_2=0$ before collision

v_1 after= $0,050$

v_2 after= 2.936ms^{-1}

S6. $v_1=3.085$

$v_2=0$

v_1 after= $0,050$

v_2 after= 2.936ms^{-1}

S7. Block A is block which is moving at start.

Block B is stationary at start.

Block A before $\approx 1.550\text{ms}^{-1}$

Block B after $\approx 1.300\text{ms}^{-1}$

S8. Velocity of Block B before collision=0. Velocity of Block A before collision=0. Velocity of Block A before collision=1550 (rough average) m/s. Velocity of Block A before collision=1300 (estimate) m/s.

S9. The moving car has initial velocity of about 1.5328ms^{-1} . The second cart is stationary. After the collision the second cart has velocity of about 1.3636ms^{-1} and the first cart is stationary.

S10. Block A is block which is moving at start. Block B is stationary at start. Block A before = 1.550ms^{-1} . Block B before = 1300ms^{-1} .

What might happen to both momentum and kinetic energy in this kind of collision?

S1. Both kinetic energy and momentum are conserved.

S2. In a total elastic collision both momentum and kinetic energy will be passed on.

S3. All momentum and kinetic energy is conserved during the collision.

S4. All kinetic energy and momentum is conserved during the collision.

S5. Energy may be redistributed but ideally nothing is lost. Energy is conserved. The momentum is transferred to the stationary body on impact.

S6. Momentum and energy may be redistributed, ideally nothing is lost to the track. Energy is conserved, total kinetic energy of the first mass is transferred to the stationary body on impact.

S7. Assuming it is an ideal situation both momentum and kinetic energy could be completely transferred from Block A to Block B.

But we can see this is not ideal as the velocity of B is less than the velocity of A.

S8. Momentum is passed on from one block to the other, nothing is lost. The kinetic energy is transferred from Block A to Block B.

S9. Momentum is conserved, although maybe a little is lost due to frictional forces. Kinetic energy should be completely transferred from one cart to the other, although some energy may be lost through sound and heat.

S10. Assuming it is an ideal situation, both momentum and kinetic energy could be completely transferred from Block A to Block B. But we can see this is not ideal as the velocity of B is less than the velocity of A.

Air Track collision 4: Use the sequence to measure how the momentum and kinetic energy of the two gliders change in the collision. Try measuring the velocities involved and deducing what happens to the momentum and kinetic energy for each of the gliders.

$$\begin{array}{lll} \text{S1. } m_1 \times -1\text{ms}^{-1} & m_1 \times 0.25\text{ms}^{-1} & m_2 = 2m_1 \\ m_2 \times 0\text{ms}^{-1} & m_2 \times -0.6\text{ms}^{-1} & \end{array}$$

It is an elastic collision- momentum as conserved but approx. 1/10J kinetic energy is lost.

$$\begin{array}{ll} \text{S2. } v_B = -1 & v_A = 0.25 \text{ blue mass } 0.19\text{kg} \\ v_B = 0 & v_A = 0.6 \text{ green mass } 0.38\text{kg} \end{array}$$

kinetic energy $m_1 = 1.5$

kinetic energy $m_2 = 1.4$

0.1 lost in experimental error.

kinetic energy $m_1 =$ kinetic energy m_2

S3. blue 1ms^{-1} to 0.25ms^{-1}

$$p = mv$$

$$\text{blue } p = 0.19 \times 1 = 0.19$$

$$p = 0.19 \times 0.25 = \quad 1/4 \text{ of the } v \text{ originally}$$

$$\text{green } p = 0.38 \times 0.6 =$$

$$1/2mv^2$$

kinetic energy

Blue

$$\text{kinetic energy} = 0.095$$

$$\text{kinetic energy} = 5.935 \times 10^{-3}$$

Green

$$\text{kinetic energy} = 0.0684$$

$$\text{kinetic energy} = 0.021 \text{ error}$$

S4. Blue

$$\text{velocity before} = 1\text{ms}^{-1}$$

$$\text{velocity after} = 0.25\text{ms}^{-1}$$

$$\text{kinetic energy before} = 0.095$$

$$\text{kinetic energy after} = 5.9375 \times 10^{-3}$$

$$\text{total kinetic energy before} = 0.095$$

$$\text{total kinetic energy after} = 0.074$$

$$\text{momentum before} = 0.19$$

$$\text{momentum after} = 0.0475$$

Green

$$\text{velocity before} = 0\text{ms}^{-1}$$

$$\text{velocity after} = 0.6\text{ms}^{-1}$$

$$\text{kinetic energy before} = 0$$

$$\text{kinetic energy after} = 0.0684$$

$$\text{momentum before} = 0$$

$$\text{momentum after} = 0.228$$

S5. M of b = 0.19kg

m of g = 0.38kg

blue Before collision K.E=0.82

blue After collision kinetic energy=0.039

S7. We take rough velocities X mass of each block

Momentum:

blue $0.19 \times 1 \text{ms}^{-1} = 0.19 \text{kgms}^{-1}$

green $0.38 \times 0.5 \text{ms}^{-1} = 0.19 \text{kgms}^{-1}$

kinetic energy

blue $\frac{1}{2} \times 0.19 \times 1^2 = 0.095 \text{J}$

Green $\frac{1}{2} \times 0.38 \times 0.5^2 = 0.0475 \text{J}$

The blue block transfers all its momentum to the green block, but it's only transferring half of its kinetic energy

S8. $0.19 \times 1 = 0.19 \text{kg/m/s}$ | Momentum is the same for both blocks.

$0.38 \times 0.5 = 0.19 \text{kg/m/s}$ |

momentum passed from blue to green. But the blue block keeps half of its kinetic energy. That is why it carries on moving.

Blue $\frac{1}{2} \times 0.19 \times 1^2 = 0.095 \text{J}$

Green $\frac{1}{2} \times 0.38 \times 0.5^2 = 0.0475 \text{J}$

S9. The velocity of the small blue glider is about 1ms^{-1} . The large glider is stationary before the collision. The velocity of the green glider after the collision is 0.627ms^{-1} . The velocity of the blue glider after the collision is -0.235ms^{-1} . Kinetic energy of blue glider before collision 0.096J. Kinetic energy of blue glider after collision 0.00525J. Kinetic energy of green glider after collision 0.0747J.

Momentum of blue glider before collision 0.19099kgms^{-1} .

Momentum of blue glider after collision $-0.04465 \text{kgms}^{-1}$.

Momentum of green glider after collision 0.23826kgms^{-1} .

S10. It is an elastic collision, momentum is conserved but approximately 1/10 of the kinetic energy is lost

Mass of small glider X velocity change of small glider.

mass of large glider

Try making measurements that will help you decide how the speed of the immobile mass (target) after the collision depends on the speed of the other one (projectile) before it and how it depends on their relative masses.

S1. kinetic energy = $\frac{1}{2}mv^2$

Velocity more important than the velocity.

S2. kinetic energy = $\frac{1}{2}mv^2$

A slight change in velocity will cause a large change in v^2 which means a large change in kinetic energy.

S3. v of green before = 1.1 ms^{-1} $p=0.418$

v of green after = 0.3 ms^{-1} $p=0.114$

v of blue after = 1.4 ms^{-1} $p=0.342$

v proportional to p if v stays constant

v proportional to p if the velocities constant

S4. v of green before = 1.1 ms^{-1} $p=0.418$

v of green after = 0.3 ms^{-1} $p=0.114$

v of blue before = 0 ms^{-1} $p=0.342$

v of blue after = 1.4 ms^{-1} $p=0.342$

total momentum before = 0.418

total momentum after = 0.456

0.038

Momentum which is effected by mass X velocity remains constant.

$m_1v_1 = m_1v_2 = m_2v_3$

S7. If the larger block was moving towards the smaller block before the collision, the smaller block would rebound and accelerate away from the larger block, the bigger the large block, the faster the smaller block travels. If you increase the mass of the smaller block, the smaller block would move away quicker, but if the masses were the same the escape velocity would be the same.

S8. The faster the bigger one is moving towards the small glider the greater the speed of the small glider will be after the collision. As the bigger one gets bigger the rebound speed of the smaller one will be greater and vice versa.

S9. If the bigger mass is moving towards the smaller mass, then the smaller mass is going to move off quicker and the larger mass is going to lose velocity, but probably still going in the same direction.

The velocity of the larger glider is given by the equation:

$$\frac{\text{Mass of small glider}}{\text{Mass of large glider}} \times \text{velocity change of small glider}$$

S10. A) Big moving towards small will have greater velocity change. big not moving, small will change velocity (through 180° turn). big moving away, small will have less velocity change.

B) For relationship masses-the change in velocity of the second glider will be in the relationship of:

$$\frac{\text{Mass of first glider}}{\text{Mass of second glider}} \times \text{velocity change of first glider}$$

Q2: Answers to the post test questionnaire

In sport activities the ball is often (but not always) much lighter than whatever is used to hit it. If you were asked to design a more effective baseball bat would it be heavy or light? Can a lightweight soccer player kick a ball as fast as a heavy one?

S3. The velocity is dependent on the distance it was to be swung. If small distance light bat for increase velocity and vice versa.

S4. The baseball bat would be heavy to create a larger momentum. No, because he can't get the momentum behind him.

Snooker or pool players can play a shot which results in the cue ball stopping as a result of a collision. How fast do you think the target ball moves after the collision?

S3. Same velocity as the cue ball.

S4. The same speed as the cue ball before collision.

How satisfied are you with how you used the MM CD ROM?

S1. I am reasonably satisfied with my use of the MM CD ROM

S2. No, I did not like the MM program, it was not explained enough. It's not as easy to ask a computer questions.

S3. It's not very accurate and some of the set-up is frustrating.

S4. Reasonably I have understood it all but the graphs are useless.

S5. It was good and very useful, especially the audio and movies but I found the velocity calculations the computer was doing fairly

confusing as it was not explained in any way. However I was fairly happy with it.

S6. Personally I am not satisfied with the way I used the programme as I found it hard to make the measurements, as I was not sure what method had to be used.

S7. I feel we used the CD fairly well but also felt I had some problems in conveying my suggestions to my partner.

S8. I am satisfied, it was easily usable, accurate and I learnt a lot from it.

S9. I think that we used the CD ROM adequately well to work out what we needed.

S10. Averagely I don't believe I used to its full potential. but if I keep using it I could begin to understand the process better and thus use it to its full potential.

S11. Not very satisfied. There was a lack of numerical calculations.

S12. I think we used it reasonably well.

What do you feel you have learnt after using the MM CD ROM?

S1. I have learnt the definition of elastic and inelastic collisions.

S2. It's very easy to mess up your data.

S3. Nothing I didn't know.

S4. It's a good way of showing experiments which aren't possible in the lab. It is very close to the real thing if not the same.

S5. I feel that I have learnt the fact that CD roms are a good way to learn and therefore shall be using them more. I have also learnt and got a clearer picture of how a CD ROM works. And more on momentum. Also what to do to get a nice set of data.

S6. I have learnt the law of conservation. It made me see how what I have learned in lessons can be used outside of lessons.

S7. I feel that I have learnt more about motion in that the CD has helped me by allowing quick and easy measurements to be taken of an experiment that is difficult to set up. It helped me also by putting figures to formulae we had been taught.

S8. I understand more clearly and have learnt more about the conservation of momentum.

S9. That momentum is conserved during elastic collisions.

S10. I think that the CD ROM has given me a slightly clearer picture. a better understanding of conservation of momentum and energy in a straight line.

Do you think that working with Multimedia Motion helps to understand better conservation laws and collisions? (Yes/No). If yes can you say how?

S1. You don't have to visualise the collision yourself, you have real-life data to play with (complete with noise) and you don't have to plot your own graphs.

S2. No.

S3. Just the same as real air track and a video on collisions but it is useful otherwise. Animation makes visualising the model more interesting.

S4. No. The acceleration graphs were not helpful because once we had created the data the graphs did not plot properly.

S5. Because it makes the learning more interesting looking at pictures and mini moving movies encourages much more

learning as it is much more interesting than looking at the text books the whole time.

S6. The 'movie' demonstrations of the experiments were informative. The audio and the text also told you the theory of conservation laws and collisions. With displacement and velocity the graphs were clear yes but with acceleration this was hard to see (because of the way it changed so erratically on the graph).

S7. It gives demonstrations of momentum changes and allows accurate measurements to be taken so that relationships between momentum mass and velocity can be explored.

S8. You can watch the collision again and again with great ease. You can take measurements easily and accurately.

S9. Because you can stop the video footage at any time and look at what is happening. It is good for learning a concept and seeing it work without experimental error.

S10. I think it gives you idealised moving pictures of situations. Which helps you to understand more fully the situation. Also the use of the timing and displacement was very helpful for working out speeds, etc.

S11. No. You see lifelike pictures so that you can actually see what happens but it would be easier to understand the concepts behind it if it were a simpler representation of the experiment.

S12. You can take accurate measurements. A problem can be made easier by using computers rather than making the experiments ourselves.

T: Samples Interaction Transcripts**Students S1: Daniel, S2: Robert**

S1. You want to point on that one so as to measure its velocity.

S2. Try one corner?

S1. Which corner?

S2. One corner.

S1. There.

S2. Just use this one first (left mass).

S1. They are the same masses, so they have the same velocity.

S2. No. Some of it might be moved over.

S1. One more point. You see it's the same velocity. 1.5m/s

S2. Measure the velocity of the object before and after the collision.

[They see again the movie. They collect data again].

S2. Click again on the bottom corner. That should be enough now.

S1. 1.4m/s.

S2. I told you it would be less.

S1. It shouldn't be just less. It should be the same.

S1. You don't lose in momentum.

S2. You do because it's not completely elastic.

S1. The kinetic energy is conserved. Momentum always is.

S2. Let's look at the second one.

S1. Let's do the green one. We know that the green is twice the mass of the blue and we want to work out the velocity of that and the velocity of that.

S2. Do we know their momentum in the first place?

S1. We know their masses.

S2. Because that is moving and it's got momentum before the collision.

S2. Do we know what the momentum is before the collision?

S1. The sequence starts here.

S2. So that's before the collision.

[They take points on the second for the second time].

S2. Why are you doing the graph before and after?

S1. This one has got some momentum. It started off...

[They go back to the graph trying to find equivalent points between the instances of the collision and points of the graph].

S1. It started moving this way with 1m/s. After the collision it was 1.25m/s. It was the same mass.

S2. Direction?

S1. Velocity is a vector, if you use it in an equation it doesn't matter.

[They disagree about who is going to operate the mouse].

S2. Go to the text and find what the mass of the blue one was.

S1. 0.19.

[They do calculations].

S2. It will be a negative figure, 1.265m/s

[They collect data again].

S1. -0.65m/s

S2. That gives us negative

[They do calculations].

S2. 1.265 square which is ... and 0.65 square which is...

S1. Kinetic energy isn't conserved.

S2. Isn't it?

S1. No.

S2. Where is it lost? Since there was no friction.

S1. Sound. No, not really.

[They look again at the graphs].

S1. This loses $0.81\text{kgm}^2/\text{s}$ in energy and this gains... No, that's not true. O.5. This loses 0.45 and this gains 0.36, so it is lost.

S2. It can't be lost. It can't.

S1. It can. It's kinetic energy It's an inelastic collision.

S2. It cannot be lost in friction.

S1. I don't know what it is lost in. There must be some tiny friction. We are talking about $1/900$ of a Joule here. It's lost somewhere.

[They go back to the sequence].

S1. Inelastic or elastic one? Which one is it inelastic or elastic?

S2. Elastic is when they come together and kick off in the opposite side and inelastic is when they stop together

[They go back to the text looking for the definitions of elastic and inelastic].

S1. It's an elastic collision while the other one was perfectly inelastic.

S1. Energy is conserved anyway, it's just converted to something else.

[They swap between the text and the sequence].

[Third task].

S1. The larger one is moving before the collision.

S1. We have to decide how the speed of. We need a different collision, we need to vary something. We need to look at the different air tracks.

S2 You need one with three times the mass.

S1. You need one with the larger mass moving. This will do... But I don't see how we can compare the sequences at all.

S2. Yeah, one with the same, one with twice the mass and one with three times.

S2. That's no elastic collision because they are moving, they are not stationary after the collision.

S1. It's perfectly inelastic. No, it's perfectly elastic... K.E is $\frac{1}{2}mv^2$. A small change in v will cause a large change in v square. And a large change in kinetic energy.

[They go back to the text. S2 unwilling to work, try to find information in the Physics literature on which the sequence is based].

S1. Wait, we take the modulus of these things, no momentum sign whenever comes up. This has got about between two or three times the momentum of this, after the collision and this is twice the mass.... Let's go back to track 4 and get some better data.

[They collect data (Green with blue stationary)].

S2. What about the forces?

S1. There is no constant force. We have uniform velocity. First law of motion.

S1. The first few. The force is acting on it.

S1. It's come from wherever it started. So in the first few... That's because the force was acting on it. The magnetism between them... There is no force on this one, so there must be uniform velocity. The first one has got force acting on it.

[They collect data, look at the graph].

S1. We can say that the ration of the momentum afterwards has to do with the ration of the mass to the combined mass. So the momentum of m_2/m_1 ... The momentum of m_2 is equal to... It's hard to express. That is three times that if you ignore the sign

which you can do, and that is twice that. And these together come up to 3, so momentum... No, it gets more complicated... Let's look at the graph of velocity, I'm lost.

[They look at graphs of velocity].

S1. This one should have twice the velocity of that. No, it shouldn't.

S2. It should have half.

[They go back to the sequence. Green (immobile) and blue immobile. They collect data again].

S1. How can it go faster? The large block moves faster than the small one. Let's just see.

S2. Of course it does. Because this one (small) is coming in, and it's giving that block its momentum with a little left for itself. So the large one will accelerate and move faster because it has the momentum.

S1. I'm not sure.

Students S3: Barry and S4: Judith.

S3. Transferring all the energy from this one to that one. We must find velocity before and after the collision.

S4. OK.

[They read the text].

S4. If you go back to the picture you can click on it, can't you?

S3. Yes.

S4. On the corner? We have to try to answer the questions. Are 4 points enough?

[They observe the graphs].

S3. This is time and distance. So it is moving at a constant velocity and then it stops. This is m/s. Velocity v_x , 1.5m/s... I'm not sure.

S4. Go back and plot some more points. This might give us an answer... OK.

[They plot some more points and then go back to the graph].

S4. It gives a better view, doesn't it?

S3. Yes, it does.

S3. Before the collision it's moving roughly at 1.5m/s ... How can you get rid of these points?

S4. Go to options.

S3. Let's move to another sequence and then come back.

S4. Right.

S3. Let's plot points on the second one. On the corner.

S4. Use the corner. It must be 1.5 again.

S3. It should be because the energy is conserved and there is no friction.

[They plot points on the second mass. They use the graph facility but not the spreadsheets].

S3. Graph of the velocity. You cannot get complete energy transfer, because it's still an air track.

S4. You have also air resistance, haven't you?

[They examine the acceleration graph].

S3. What's that?

S4. I don't know.

S3. It's reasonably constant. Slightly under 1.5m/s .

S4. The other one was just above, wasn't it?

S4. Just under 1.5 should be the thing to say.

S3. It is 1.25m/s .

S4. 1.3 .

S3. It's supposed to be 1.5 though.

Second task.

S3. What about that? They are conserved.

S4. Should be kinetic energy, energy because of motion.

S3. That stopped completely.

S4. Yes, all the momentum and all the kinetic energy has been transferred.

S4. All the momentum and all the kinetic energy has been transferred.

S3. Energy and momentum is conserved during the collision.

S4. Air track collision 4.

S4. Momentum is mass times velocity.

S3. I guess the green mass is twice the blue one.

S4. We can find from the data.

[They collect data again].

S4. If we work out the momentum before and after the collision, m_1v_1 equals, no... There should be a change in velocity of the blue one because it has a smaller momentum and it gives something to the green one.

S3. This velocity plus this velocity should equal the original velocity of the blue.

S4. The original momentum, because you have to account for the mass... Something like that.

[They examine the graph of v_x].

S3. This m/s

S4. It's going backwards.

S4. 1m/s.

S3. And it finishes after the collision at 0.25m/s.

S4. So velocity before is 1.0m/s. Velocity after is 0.25.

S4. Let's go to the text to get the mass for the momentum.

S3. Mass 0.19 multiplied by 1 and after 0.19 multiplied by 0.259.

S4. And the momentum after equals 1.25 times 0.19.

S3. Let's do the green one on the same graph.

S4. Can we?

S3. We can see how they compare.

S4. Yeah.

[They collect points and then examine the graphs].

S4. I think that part is the green one and that is the blue one. I think it must be 0.6 or 0.7.

S3. Let's go back to the sequence and plot some points again.

They choose the upper right corner of the big mass. Go to the graphs.

S3. Let's do a_x ... It fluctuates.

S4. It should be constant, shouldn't be... Let's do v_x .

S3. This is constant.

S4. Very reasonably constant... That's all we wanted, wasn't it?

S3. No, because that's going up and down on the y axis (v_x), it's not like moving up and down, it's really on the x axis... Let's try acceleration (a_x and a_y).

[They go to spreadsheet and after that to the text].

S3. Momentum before of the first mass 0.19 and after was... Momentum after is much less, because it's not travelling as fast. It's travelling at a quarter of the original speed... so the other one (green) 0.38 times velocity equals 0.6.

[Third task]

S4. It says how it depends on the relative masses, the only way to join the speed and masses together is to get momentum..

S3. We worked the velocity of the green before and after the collision.

[They collect data again].

S4. This mass is reluctant to leave.

S3. Obviously it's going faster than the green. The mass is less.

S4. It has a smaller momentum.

S3. No, they have the same because it's going faster. It should be the same.

[They examine the v_x , v_y , a_x and a_y graphs].

S3. 1.3 or 1.4 m/s.

S4. Let's put 1.35.

[They calculate momentums].

S3. What's the kinetic energy of the green.

S4. You don't need the kinetic energy.

S3. And the momentum.

S4. Momentum for the green before was 0.1418 before and 0.194 after. For the blue, momentum before was 0.00 and after 0.342.

S3. If you take away the velocity of the green one afterwards and the momentum of the green one afterwards...

S4. What about the total momentum before and the total momentum afterwards?

S3. It's $0.194 + 0.342 = 0.456$ which is...

S4. It should be the total momentum afterwards.

S3. Which is 0.38 out. So, that's pretty good actually... The momentum is conserved throughout the collision and...

[They look back at the task].

S3. So we worked out that the mass and the velocity both affect the momentum, for if the mass is larger and the velocity stays the same, the momentum of the blue one afterwards is going to be greater....

S4. Despite the size it will have a larger velocity.

S3. ... and if the mass stays the same and the velocity is increased, this is going to be larger (blue one)... and if either of the two is increased... and this (the blue one) is gonna get smaller...

S4. Momentum is conserved despite... Momentum is affected by... mass and velocity, but it's constant.

S3. We can say that momentum is proportional to velocity, can we say that?

S4. Of course we can say that.

S3. It's only proportional if the mass stays constant... and mass is proportional to momentum if the velocity stays constant.

S4. That will do.

Students S9: Roger and S10: Ray

[First task]

S9. Let's play it first to see what happens. We need a point... This one comes in, stops ...To see what happens to the velocity of this one as it comes in.

[They choose points at the upper right corner of the first one. Then they go to the spreadsheet].

S9. They actually collided there.

S10. They haven't collided. Have they? They haven't quite touched.

S9. The y-acceleration and velocity we don't care about. That's fine.

S10. What about this 0.7?

S9. It's only because you are moving up and down, when you click on a point out of line.

S10. OK.

S9. Do you want to take some more readings or should 5 be enough. Let's take five to make it more accurate since it doesn't take long.

[They go back to the spreadsheet].

S9. 1.5m/s. Let's calculate. All velocities divided by 5.

[They calculate average velocity].

S9. What momentum and kinetic energy? Before the collision.

S9. Momentum is conserved, isn't it? There is a slight loss, because of friction.

S10. And air resistance?

S9. Air resistance shouldn't cause much of a problem, but there may be some kind of affection (sic) which accounts for 0.8m/s.

S10. Kinetic energy is just transferred. Isn't it?

S9. Kinetic energy is transferred from first to second. There may be a slight loss through sound.

[Second task]

S10. One mass is double the size. If we could just play that again.

S9. This one comes shooting off. There is an inelastic collision, a partially inelastic collision... The first one is twice the size of the second one.

S10. The momentum. Some of it is transferred to the bigger one, some of it. Do we know the masses?

S9. We just have to assume that it's proportional to the size.

S9. Velocities before and after.

[They collect data from the second one. They do more calculations of average velocities].

S9. This one is gaining $\frac{2}{3}$ of the energy of the other one if it's double the size. If it's a frictionless collision, then the green one

moves off at $1/3$ of the original; velocity of the blue one. The blue one will travel backwards with the same speed. Won't it?

S10. Not the green one will go off at ... $1/3$ going left and $2/3$ going right.

S9. No, $2/3$ going left but it's double the mass. Basically they will be travelling both with the same velocity. Aren't they?

S10. How come? Because this one is bigger, isn't it?

S9. What I thought was happening is that the blue one is coming in moving with a velocity of 3 units and then it transmits 2 units to this and keeps one itself and is going back. So this is moving off with 2 per unit of mass. And this (blue) has got 1. As this is double (green) therefore overall of 1.

S10. What about K.E? For the blue one... Because the other one is heavier, its velocity is less... When they hit, half going left, half going right.

S9. Let's just go for kinetic energy. We'll then know how they actually get distributed, whether it's half way either way, or what ratio. So let's work out some velocities.

S10. Let's reset.

[They collect data. They go to the spreadsheet and calculate velocity averages].

S10. Roughly 1m/s .

S9. Velocity of the right one should be... Velocity of the green one is 0m/s . And after the collision velocities are.

S9. They are slightly in contact there. They are still in contact in the first reading. So we will have to ignore the first reading.

[They calculate averages for velocity. Then they collect data for the blue one].

S9. 2.7.

[They calculate K.E].

S9. I'm doing it completely wrong. I'm doing a blue glider with the mass of the green one. We got kinetic energy. There must be a loss somewhere along the line. We lost 0.15... No, velocity of the blue one afterwards we have 7 readings for it, so the accuracy is not too bad... Kinetic energy has been lost through sound and friction. We've definitely lost something.

[They collect data again].

S9. We got 0.235.

S10. But if we get that squared.

S9. We've lost kinetic energy along the line.

S10. Through frictional forces.

S9. It could be friction... We actually have conservation of momentum, haven't we? If you think about it, to begin with, the blue one is coming in this way and afterwards the green one's going this way and the blue one is going back out. So the momentum of the blue one afterwards should be negative. We take the direction to the left to be positive.

[They do calculations of total momentum].

Third task

S9. It's asking how the speed of the large one gives energy to the smaller one.

S10. Because momentum is conserved, it should be the same one before and after. Total momentum has got to be the same.

S9. So if the green one is moving quite quickly, it will slow down, the blue one will move very quickly. Whereas if the green one is moving slowly, the blue one will still gain more speed because it's lighter.

S10. As long as the green one is moving towards the blue one, the blue one will speed up quicker and the green one will slow down.

S9. The blue one will either stop or go back if it's only a slight touch... Actually no...

S10. If the blue one is going slightly faster than the green one, after the collision they will still be going in the same direction.

S9. Because it's an elastic collision, isn't it? If the green one is going same direction, it's going to slow it or return it.

S10. If the green one is going to the left, this one (the blue) must have greater momentum than the other one because it has to catch up.

S9. Yes, it's got to hit it.

S10. Both of them will have the same momentum before and after the collision. Actually the blue one will have more because it is going faster.

S9. Yes, velocity has got to be more.

S10. The mass didn't change, the momentum didn't change, the only thing that changed is the velocity.

S9. The total momentum won't change. We cannot really vary any of the masses or speeds, can we? Since we cannot vary any of the things we've got, the measurements we can take except for acceleration, which we know basically what will do. This one (green) will accelerate away, no, it will decelerate and then accelerate. There are no measurements you can take.

S10. Actually accelerate when they hit, But they have the same (constant) speed. They slow down as soon as they hit, but they have constant speed.

S9. But they decelerate in the collision and accelerate out.

S10. In theory, the velocity is constant.

S9. It depends on the speed of the bigger one. You cannot change that... So you cannot actually take any varying measurements, so we've got everything we can do... The whole thing is based on Collision 4. Isn't it?... We've got all the measurements we need.

S10. One is going quicker than the other one and they hit.

S9. Basically is as the energy has travelled through it...Relative mass is easy, just how much is spread out. If one is significantly larger than the other one, it's going to take more energy to move it. If it hits, it will transfer a lot more energy.

S10. If it was 1000 times larger and the small one is hit with a tiny force, it would still move it.

S9. It would still move it... The relative mass is dependent on the ratio of the two masses, isn't it? There are three things we can vary in the first one, which are the three ways the bigger one moves before the collision, towards, none or away.

S10. Yeah?

S9. What we can answer, is the three ways it could be moving and how it's likely to affect it... If the big one is moving towards it, we will have a greater velocity change, since it's coming in and being pushed out as well, whereas if it's moving away it will come in and cushioned out. So, we have smaller velocity change. We cannot actually state what the change is gonna be, we can say relatively. If this one is not moving, when this one comes in, it will have a velocity coming out as well, won't it?... And if one is moving towards, when this comes in, it will have a greater velocity than if this one wasn't working. You can't actually put a value on it, because we don't know how much is moving towards and away.

S10. If momentum is conserved.

S9. Well, momentum is conserved we know that... In fact the blue one has always got to go back, the other way, hasn't it? cuz there is going to be a collision.

S10. No, if that one (green) is going this way (left), the blue one will catch up.

S9. Yeah, it will still be going quicker.

S10. Yeah, but if it's going slightly quicker and pushes the other one faster.

S9. Yeah? It could push it and hit it off but, it could follow it. There is no way when the green is stationary, this one can come in and keep going. It has to turn around, if the green one is stationary.

S10. The small one always has to rebound if the green one is stationary.

S9. Yeah, if the green one is stationary the other always ends up going in the other direction. I'm trying to think of a relationship. If it has a smaller mass than the one it hits, then the larger one will move off slower... If we look at momentum equals mass times velocity. The momentum of this and this before will be the same as after. This (blue one) has all the momentum to begin with and in a perfectly inelastic collision or is it elastic? Well, when all the momentum is transferred over... so the mass of the small one over the mass of the bigger one. so, the mass of this one is divided by a larger number. cuz let's suppose this comes in always with the same velocity and if the mass of this is significantly heavier, it will be divided by a larger number, so it will give a smaller velocity. So, for the relationship of the mass, it's the velocity of the second glider... Actually it will be the change of velocity in the second glider...

IT: Interview transcripts**1**

S1. I liked the actual movie. The only down point is you don't get errors... The graphs themselves were not very useful. A graph is helpful. You can relate back to what you remember. You need the graphs, but the graphs were not good enough. If you compare to the lab. You cannot in the lab get the accuracy of the simulation. But if the lab was properly organised you could explain it in an easier way, because you would be doing it yourself. It would be the same only very accurate in MM. If there is a proper equipment in the lab it would probably be better because you would relate to it.

R. Do you think it is more helpful to have boxes instead of objects.

S1. It's easier to understand the phenomenon if you see realistically looking objects.

2

R. would you trust the computer

S4. Yes, if the models were well made.

R. What about the graphs?

S4. They show in change of direction... You just make the simulation to look more realistic. There is not much difference. A simulation helps you relate more to real life.

R. Did you do any similar experiments in the lab?

S4. Not really.

R. Do you trust the computers you get on the computer screen.

S4. Yes, I trust them more.

R. Were the graphs helpful?

S4. They were but I did not use them. The digital values were more useful. In general a graph helps, it shows a general pattern.

3

R. What about the third task? Was it difficult or an easy one?

S5. I found it quite easy.

R. What do you think of MM?

S5. It was good.

R. What about the graphs facility? Did you find them useful?

S5. ...I think it would be good if you could have some way of totalling things up or finding gradients.

R. So you did not use the graphs at all?

S5. Not really.

R. Have you worked with graphs in the past?

S5. Yes.

4

R. What do you think of the whole experience?

S8. The simulation? I quite enjoyed it. If I had been taught in this way from the start, it probably would be better than just reading from a book. Normally you know when you choose velocity and see what happens

R. Did you find the 3 explorations for momentum and the gliders, did you find them helpful in understanding conservation of momentum?

S8. Watching the movie yeah. plotting and using the graphs, no.

R. So do you think that using the graphs wasn't very helpful?

S8. They didn't show any pattern even with the same point, they were so scattered. The line of the best fit didn't make sense. So when you put it into the formulae you get the calculations out, the accuracies is just not there.

R. So you think the graph is helpful?

S8. Yeah.

R. Did you find you could easily see the how the graphs corresponded to the movie sequence?

S8. Yes.

R. So you think you need the graphs but these graphs weren't good enough for giving you much help.

S8. Yes they were too sensitive. You couldn't look at the graphs and understand what they were trying to represent.

R. Which of the graphs were more helpful?

S8. The acceleration and the velocity on x but the y graphs were usually so scattered it didn't make sense.

R. Why was that do you think?

S8. I don't know, to be honest. Maybe because of the axes.

R. Because the motion was on the x-axis instead of being on both axes you mean?

S8. Yes.

R. If you compare MM with same linear collisions on air tracks but in the lab, do you think doing it in a lab is more useful/helpful than doing it here?

S8. I don't know really. In the school labs you couldn't really achieve the accuracy of the timing of the velocity versus accelerations.

R. Yes, that's a good point.

S8. If you had proper conditions in the lab to do this sort of experiment could be more easier to explain because you would be doing it yourself. It would be the same, it's just that the simulation is very accurate.

R. So you'd rather do the experiment with the computer simulation than in the lab.

S8. Well we have done it in the lab but it wasn't very good. If we had the proper equipment in the lab it might have been better, because you can relate to it by watching it scene by scene, visualising it.

R. I guess you have seen other simulations instead of having a video, like here where it is very realistic, it's happening in front of you. If you had a simplified experiment on the computer screen, simple shapes like circles or squares which collide. Do you think it's more helpful or manageable having like that?

S8. Yeah. If you could run a full screen movie and actually plot on the movie. But the movie is so small you can't actually relate to it.

R. Yes but if you make it bigger you lose the quality of the picture. So do you think it's easier to understand the phenomenon if you see a realistic video?

S8. I guess so. But even watching virtual reality is still not the same as watching the real thing. Like when the space shuttle blasts off you get so far through it then the smoke shields it off. Also because of the fixed point camera it actually goes off the screen, so you don't see all of what you are looking at.

R. You were also saying that the movie screen was quite small and you couldn't see the sequences in detail.

5

R. What do you think of the program?

S10. I found it a bit complicated to work with it out. I wasn't sure how it worked. Other than that it was good. I liked the way it explained thing.

R. Did you find the questions difficult?

S10. I felt I should know them but I didn't.

R. Do you think the programme helped you in completing the tasks?

S10. Yes.

R. Tell me what you liked about it? Or any things you did not.

S10. I liked the movie and the text that tells you all about it, the theory behind it all. I didn't like the trying to work out the calculations, e.g. kinetic energy, because I wasn't sure what the screen showed and which way it did it, that was the only part that was frustrating... I also didn't know what points to choose but that could have been my fault.

6

R. Tell me about the program?

S11. Very good. Clear to understand. I've never used computers before.

R. You haven't used anything like that before?

S11. No. I'm not into computer stuff.

R. Do you think it helps to understand collisions?

S11. Yeah. If I hadn't done physics, I wouldn't have known as much to start with but even so there are things the simulation taught me.

Appendix 5

CirclesColliding (CC)

| | |
|--|----|
| Data catalogue | 1 |
| Q1: Pre test Questionnaire | 2 |
| W: Interaction worksheet..... | 15 |
| Q2: Post test questionnaire | 21 |
| T: Samples Interaction Transcripts..... | 27 |
| Students S15: Anthony and S16: Martin..... | 27 |
| Students S19: Gordon and S20: Peter | 30 |
| Students S23: Philip and S24: Nigel | 33 |
| Users S25: Maria and S26: Rick..... | 34 |
| IT: Interview transcripts | 38 |

Participants

CC1

| | | | |
|------------|---------|------------|---------|
| S13 | Mike | S14 | Carol |
| S15 | Anthony | S16 | Martin |
| S17 | Helen | S18 | Rosie |
| S19 | Gordon | S20 | Peter |
| S21 | Patrick | S22 | Matthew |
| S23 | Philip | S24 | Nigel |

CC2

| | | | |
|------------|-------|------------|------|
| S25 | Maria | S26 | Rick |
|------------|-------|------------|------|

Data catalogue

| School | Students | Type of data |
|----------|----------|------------------------|
| School B | S13 | 1, 2, 3, 4, 5, 7, 8 |
| School B | S14 | 1, 2, 3, 4, 5, 7, 8 |
| School D | S15 | 1, 2, 3, 4, 5, 6, 7, 8 |
| School D | S16 | 1, 2, 3, 4, 5, 6, 7, 8 |
| School D | S17 | 1, 2, 3, 4, 5, 6, 7, 8 |
| School D | S18 | 1, 2, 3, 4, 5, 6, 7, 8 |
| School D | S19 | 1, 2, 3, 4, 5, 7, 8 |
| School D | S20 | 1, 2, 3, 4, 5, 6, 7, 8 |
| School D | S21 | 1, 2, 3, 4, 5, 6, 7, 8 |
| School D | S22 | 1, 2, 3, 4, 5, 6, 7, 8 |
| School D | S23 | 1, 2, 3, 4, 5, 6, 7, 8 |
| School D | S24 | 1, 2, 3, 4, 5, 6, 7, 8 |

CC2: Users

| | |
|-----|------------------------|
| S25 | 1, 2, 3, 4, 5, 6, 7, 8 |
| S26 | 1, 2, 3, 4, 5, 6, 7, 8 |

Key to data categories:

| | |
|--|---|
| Observation schedule | 1 |
| Student computer and science questionnaire | 2 |
| Student pre-program questionnaire | 3 |
| Student post-program questionnaire | 4 |
| Student interaction worksheet | 5 |
| Notes | 6 |
| Video tape | 7 |
| Interview audio tape | 8 |

Q1: Pre test Questionnaire

Have you got any previous experience with computers (e.g. for word-processing)? yes/no. If yes give some examples of your experience.

S13. Using Claris works on the Macintosh

S14. Writing up coursework for GCSE. I run the computer club for the lower years. I own a computer at home and have used it for games and homework

S15. I have used word processing and spreadsheet programs (e.g. Microsoft, Excel) mainly for homework.

S16. Used Word and Excel for school work.

S17. No

S18. An Amstrad PC at home, school computers, spreadsheets, word processing.

S19. word processing, coursework for numerous different subjects, lately I started writing my homepage, I wrote a computer game for my coursework.

S20. No

S21. I have used a word processor for about 10 years and am quite competent with their uses, both for basic word processing and more advanced functions such as mail merge etc. I also use spreadsheets, databases and communication packages (e-mail etc.)

S22. Used word applications up to word 6.0 including Microsoft Excel, Microsoft access. Also use a lot of Desk top publishing e.g. Microsoft Publisher GST Pressworks

S23. Databases in business studies, Word processing, general homework.

S24. Use of PC at home for writing up school work.

S25. Programming, wordprocessing, email.

S26. Programming in C, course teacher, system administrator on Unix network.

What sort of science courses have you done in school?

S13. Biology, Chemistry, Physics, A-level

S14. General GCSE course of Biology, Chemistry, Physics and environment and A level course Chemistry, Physics. Also doing a Science CREST Award.

S15. GCSE combined Science and A level physics.

S16. Physics.

S17. GCSE double science

S18. Double Salters Science award.

S19. GCSE Salters science. A level physics: electricity and mechanics, particles and waves, further physics, materials physics.

S20. Momentum experiments using sensors linked to computers. GCSE Salters Science double award, A level physics, material physics, DC electricity and Mechanics.

S21. GCSE Salters science Double award.

S22. GCSE Salters science (double award) ranging from Biology, Chemistry and physics.

S23. Physics science. A-level GCSE double science.

S24. GCSE double Science award. A level physics, Chemistry.

S25. Secondary science education. First degree in Physics.

S26. Physics BSc, Chemistry, Biology A levels.

Have you ever used a computer simulation? Yes/no. If yes, explain and say what you think a computer simulation is.

S13. No.

S14. No.

S15. A simulation I think is a program designed to model a real life situation in the computer's memory.

S16. No

S17. No.

S18. No

S19. No.

S20. No

S21. No.

S22. A computer simulation is when a computer takes a real life situation and simulates it. This means that a person can carry out the activity without having actually to do the activity in real life.

S23. No.

S24. A program for modelling a situation that could happen in real life.

S25. A virtual laboratory.

S26. A simulation on a computer.

Can you say what is meant by a conservation law? Can you give any examples of conservation laws?

S13. Before. Conservation of momentum is a law as in the conservation of energy. A conservation law might be a law where e.g. in an elastic collision momentum is conserved.

After. A conservation law is a law in which all of a value, i.e. momentum must be conserved within a system.

S14. B. Conservation law means that nothing is lost, it has been changed or conserved e. g. energy: energy cannot be destroyed but can be changed and conserved, e.g. conservation of energy , conservation of momentum.

A. Conservation of momentum, conservation of energy, etc. A conservation law means, e.g. energy is not lost or destroyed it has been transferred to another object.

S15. B. A law describing how a property is conserved e.g. conservation of energy or momentum.

A. A rule about how something is conserved energy momentum often applies to collisions of objects.

S16. B. A conservation law deals with the energy involved in the collision of particles. In a collision both momentum and kinetic Energy are conserved.

A. Conservation law states that momentum and kinetic energy will be conserved in an elastic collision.

S17. B. No.

S18. B. Momentum is conserved after a collision ($m_1v_1=m_2v_2$)

S19. B. No.

A. Energy is conserved in a collision and so is momentum.

S20. B Energy is conserved in perfect elastic collision, momentum is conserved $m_1u_1=m_2v_2$

A. Energy is conserved in a perfect elastic collision. Momentum is conserved only in a perfect elastic collision.

S21. B. Conservation of momentum, the total momentum before a collision is equal to the total momentum after the collision.

A. Conservation of momentum. Total products of mass and velocity for each object is equal before and after the collision.

S22. B. A conservation law is where no energy is lost. An example being a collision where no kinetic energy is lost.

A. Conservation law is where the energy in a system is conserved. An example is an elastic collision.

S23. B. An energy is conserved what you put in is what you get out, no energy is lost due to forces, e.g. friction.

A. Same as before

S24. B. Something is preserved cannot be reduced increased in magnitude. Conservation of energy cannot be created or destroyed. only changed from one form to another. Conservation of momentum before the collision = momentum after collision.

A. Same as before

S25. A law where both sides of the equation add up. Conservation of momentum. Conservation of mass. Conservation of energy.

S26. A conservation law states that property that remains constant through a process, e.g. momentum is conserved if no external forces are applied to a set of masses/objects.

If you have two equal masses moving at the same speed and colliding what will happen after the collision?

S13. B. Both objects collide and separate moving off at the same initial speed and in the opposite direction.

A. Same as before.

S14. B. Both masses will go in an opposite direction at the same speed.

A. Perfectly elastic collision occurs. Both masses will collide, they will both move off in an opposite direction, both travelling the same speed. This occurs due to the same mass and same original speed.

S15. B. They will stop at the middle or bounce at equal speeds in the opposite direction.

A. Bouncing will occur.

S16. B. They will move away from one another at equal speeds and in opposite directions to which they approached.

A. They will both retain the same momentum they had before the collision but in opposite directions.

S17. B. They will move away from each other at a slower speed.

A. They will move at a slower speed.

S18. B. The two masses will rebound off each other and travel in the opposite direction to which they were travelling.

A. They will rebound and continue moving at a constant speed.

S19. B The two masses will bounce off each other.

A. The two masses will bounce back off each other with same velocity.

S20. B. They will both move in the opposite direction with the same velocity. It is a perfect elastic collision and the kinetic energy will be conserved.

A. They will both move away in the opposite direction at the same velocity. Both momentum and kinetic energy are conserved in the perfect elastic collision.

S21. B. They will be propelled backwards in a straight line with their velocities identical to their velocities before the collision.

A. After the collision object x will move away from point p with velocity of $-a \text{ ms}^{-1}$ whilst y will rebound with velocity $-b \text{ ms}^{-1}$. Momentum is conserved.

S22. B They will move apart.

A. Both will bounce apart at equal velocities. Kinetic energy is conserved as is momentum.

S23. B. They will separate at the same distance apart, going in the opposite direction they came.

A. Same as answer put on other page.

S24. B. They will remain at point of collision i.e. will not stick and move together and will not bounce back.

A. They will bounce back with the opposite velocity.

If a small mass collides with a much bigger immobile mass what will happen after the collision?

S13. B. The small mass will hit the larger one and then will move off in opposite directions with some momentum been transferred from the smaller to the larger mass.

A. Some of the momentum will be transferred from the smaller mass to the larger one and after the collision the masses will move off in opposite directions with the smaller mass travelling faster than the bigger one.

S14. B. The small mass will rebound off the large mass and move in the opposite direction. The large mass may move.

A. The small mass will set the bigger mass moving in a +ve direction. due to the moving object having a smaller mass it rebounds off in a -ve direction. The small mass transfers a lot of energy to the larger mass.

S15. B. The small mass will have lost energy but may bounce back. It should stop, transferring all energy, however.

A. Small mass will bounce off.

S16. B. The small mass will rebound off the larger mass which itself will move fractionally in the original direction of the smaller mass.

A. The smaller mass will rebound whilst the larger mass will move at a speed, in the original direction of the smaller mass, proportional to the difference in masses of the two. The difference in their velocities will equal the original velocity of the smaller mass.

S17. B. The smaller mass will stop.

A. The small mass will stop.

S18. B. The masses would stick together and move very slowly.

A. The masses will move very slowly to the right.

S19. B The small mass will bounce back after hitting the larger mass. The larger mass will stay still.

A. The smaller mass will bounce off the larger mass but it will transfer some of its momentum to the larger mass.

S20. B. The smaller mass will rebound back off the larger mass. The larger mass will move only slightly maybe not at all.

A. The smaller mass will rebound at a lesser speed than it began and will transfer its loss in speed to the larger mass. Kinetic energy is therefore conserved. But momentum is lost because there is an uneven balance in the +ve and -ve velocities.

S21. B. The smaller mass will be propelled away from the larger mass with the same velocity as before.

A. After collision the velocity of the smaller object and its initial velocity = the final velocity of the bigger object.

S22. B. The small mass will bounce back of the large mass and the large mass may move in the opposite direction.

A. The velocity of the bigger mass will increase and the smaller mass will go in the other direction. The velocity of the bigger mass is the velocity at the start minus the velocity after.

S23. B. The big mass will move a little to the right whereas the small mass will move a lot more to the left than the big mass did to the right.

A. The small mass will move to the left with a lower velocity, and the big mass will move to the right with a lower velocity compared with that of the small mass. Energy will be conserved, if none is lost to friction, sound.

S24. B. Both will proceed in the same direction at a lesser velocity, (inelastic), or larger mass will travel right at a lesser V , and small mass will bounce left (elastic)

A. Elastic, larger mass will travel right at a lesser V , and small mass will bounce left (elastic).

If a big mass collides with a small immobile mass what will happen after the collision?

S13. B. Some momentum is transferred from the longer mass to the smaller one and they move off in the same direction.

A. After the collision the smaller mass moves off with much faster velocity than the big mass before the collision. Both masses move in the same direction after the collision.

S14. B. The large mass will push the smaller mass in the same direction. **A.** The large mass will collide with the small mass sending it in a +ve direction. The smaller moves off a lot faster than the larger mass because it is a lot lighter. A lot of energy has been transferred from the larger mass to the smaller. The larger mass slows down because of this transfer of energy.

S15. B. The same thing as in second question.

A. Big mass will bounce off.

S16. B. The large mass will lose little momentum due to its greater mass whilst the smaller mass will gain significant momentum from the collision. Both will be moving in the same direction after the collision.

A. The larger mass will continue to move in the same direction but at a slower velocity whilst the smaller mass will move in the same direction but with a greater velocity. The difference in their velocities is equal to the original velocity of the larger mass.

S17. B The big mass will stop.

A. They will both travel in the same direction.

S18. B. The masses will again stick together and move, but this time they will move only slightly slower than the large mass was moving on its own.

A. The masses will stick and move to the right, but they will move only slightly slower than the large mass was moving on its own.

S19. B. The big mass will keep moving in the same direction and with less velocity. The small mass will go with the larger mass.

A. The larger mass will push the smaller mass but with less velocity than it started with. The smaller will move with exactly the large mass' initial speed plus the larger mass' ending speed.

S20. B. They will join together as one mass and move in the direction that the big mass was travelling. This is an inelastic collision.

A. The larger mass will considerably slow down but the small mass will move with a speed much quicker (even more than the larger mass began with). the relationship is that the smaller mass will move $x\text{ms}^{-1}$ faster than the larger mass where $x =$ the velocity of the large mass at the beginning.

S21. B. The larger mass will move away from the smaller mass with velocity as before, on the momentum of the smaller mass is 0, the momentum of the larger mass will be conserved, i.e. the mass will stay constant. The velocity remains unchanged.

A. Momentum is not conserved. The smaller object attains greater velocity than the larger mass. They will move to the right. The sum of the momentums after collision divided by the initial velocity of the smaller objects produced a number ranging $6.4 \leq 6.464 \leq 6.5$ with 6.464 the most commonly attained number.

S22. B. Both will move in the direction of the larger mass with the smaller mass being shared by the larger mass.

A. The small mass will take the velocity of the big mass before the collision and the velocity of the big mass after the collision. Both will travel in the same direction.

S23. B. The big mass will only move a little to the right whereas the small mass will move a lot to the right.

A. The bigger mass will move with a lower velocity after the collision than it did before, however the small mass will move with a greater velocity than the original velocity of the big mass and will move to the right.

e.g. before 10 g 5ms^{-1}

after 10g 2.86ms^{-1} , 2g 6.86ms^{-1}

Energy will be conserved if none is lost due to energy, heat energy, sound.

S24. B. $Mv_1 = (M+m)v_2$ $Mv_1 = Mv_3 + mv_4$

They will either proceed in the same direction at the same (lesser) velocity (inelastic collision) or they will proceed in the same direction, the smaller mass moving at a greater speed than the larger mass (elastic collision).

A. Not only will the small mass move faster than the large mass after collision, but it will also be moving at a velocity greater than the large mass had before the collision.

CC2 questionnaire

If you have two equal masses moving as in fig 1, can you say what will be the outcome of the collision.

S25.

S26.

What initial speed these two masses must have in order to change direction of motion (from moving on the x-axis to the y-axis and vice versa) after the collision.

S25. Equal speeds.

S26.

What is the minimum speed the masses must have in order to collide?

S25.

S26.

W: Interaction worksheet**Collision 1**

Explore the sequence and see if you can measure the velocities of the objects before and after the collision.

S13. Changed velocity to -5.00 on 10kg 2 x-velocity. kept 10kg 1x-velocity the same. Run simulation and used freeze frame function to watch up to pair of collision frame by frame and observed changes in $|v|$ and v_x on velocity boxes of 10kg 1 and 10 kg 2.

S14. $m_1u_1+m_2u_2=m_1v_1+m_2v_2$

Collisions are perfectly elastic . we looked at the collision with both masses and speeds being the same. We noticed they both left after the collision at the same speed but in different direction. We then changed the speed of one and noticed in the collision they both swapped speeds. Perfectly elastic collision, transfer of energy. momentum and kinetic energy are transferred. Perfectly elastic.

S15. Initial velocity of object 1 is 10ms^{-1}

Initial velocity of object 2 is 5ms^{-1}

After collision of object 1 is 5ms^{-1}

After collision of object 2 is 10ms^{-1}

S17. Initial velocity of object 1 is 10ms^{-1}

Initial velocity of object 2 is 15ms^{-1}

After collision velocity of object 1 is 5ms^{-1}

After collision velocity of object 2 is 10ms^{-1}

S18. $v_1=3.085$

$v_2=0$

$v_1 \text{ after}=0,050$

$v_2 \text{ after} = 2.936 \text{ ms}^{-1}$

S19. before first cart $v_1 = 1.5328 \text{ ms}^{-1}$

before second cart $v_2 = 0 \text{ ms}^{-1}$

after first cart $v_1 = 0 \text{ ms}^{-1}$

after second cart 1.3636 ms^{-1}

S20. Velocity of Block B before collision = 0. Velocity of Block A before collision = 0. Velocity of Block A before collision = 1550 ms. Velocity of Block A before collision = 1300ms.

S21. The moving car has initial velocity of about 1.5328 ms^{-1} . The second cart is stationary. After the collision the second cart has velocity of about 1.3636 ms^{-1} and the first cart is stationary.

S22. Block A is block which is moving at start. Block B is stationary at start. Block A before = 1.550 ms^{-1} . Block B before = 1300 ms^{-1} .

What might happen to both momentum and kinetic energy in this kind of collision?

S13. Momentum and kinetic energy are transferred in this type of collision.

S14. Momentum and kinetic energy are transferred. Perfectly elastic.

S15. They are conserved.

S16. In this collision, both are conserved as overall mass and velocity remains constant.

S17. Momentum's conserved. Kinetic energy is transferred between the masses, they swap velocities on collision..

S18. Momentum is conserved, kinetic energy is transferred from one mass to the other. Velocities are swapped over.

S19. In all these cases the kinetic energy is transferred from the two masses.

S21.

S22. Both were conserved because both were dependant on mass and velocity which remained constant.

S23. In this collision both kinetic energy and momentum are conserved, no energy is lost due to friction, sound heat etc. the collision is perfectly elastic..

S24. In elastic (perfect) collision momentum and kinetic energy is conserved.

Collision 2

Use the sequence to measure how the momentum and kinetic energy of the two masses change in the collision.

Try measuring the velocities involved and deducing what happens to the momentum and kinetic energy for each of the masses.

S13. In collision 2 kg 2 keeps 3/5 of its total momentum after collision and 8kg 1 gains 2/5 of momentum after collision. elastic collision. Kinetic energy has a ratio of 2:1 after collision with 8kg 1 having ≈ 2 as much kinetic energy the 2 kg 2.

S14. Mass 2kg decreases in energy after collisions. It transfers some of its energy at the point of collision. Mass 8kg increases in energy at point of collision energy is transferred. By doing a few run throughs of the collision with 2kg having different speeds we worked out that it transfers 2/5 of its speed and moves off with 3/5 of its speed in the opposite direction.

| | | | |
|----------------------|----------|----------------|---------------------|
| S15. Before 1 | 10ms-1 | after | -6ms-1 |
| 2 | 0ms-1 | after | 4ms-1 |
| momentum | 20kgms-1 | 32-12=20kgms-1 | momentum conserved. |

kinetic energy $\frac{1}{2} \times 2 \times 100 = 100$ $\frac{1}{2} \times 2 \times 36 + \frac{1}{2} \times 8 \times 16 = 100$ energy conserved.

S16.

momentum of object 1 is 20kgms-1 Initially =20

momentum of object 2 is 0

momentum of object 1 is 12kgms-1 After =20.

momentum of object 2 is 32kgms-1

Momentum of object is same before and after therefore conserved.

Kinetic energy is also conserved.

S17. Velocity ratio=2:3 adds up initial velocity (without the sign).

Mass ratio=1:4.

S18. Ratio of velocities after collision =2:3 (before)

e.g. $10\text{ms}^{-1} = v$ of $2\text{kg} = -6\text{ms}^{-1}$

v of $8\text{kg} = 4\text{ms}^{-1}$

ratio of masses=1:4

S19. For all of these cases the kinetic energy and the momentum transferred from the small to the large. And it loses momentum because it isn't a perfect elastic collision.

S20. The kinetic energy is conserved in the collision.

The collision loses momentum.

S21. The velocity of the small blue mass is about 1ms^{-1} . The large mass is stationary before the collision. The velocity of the green mass after the collision is 0.627ms^{-1} . The velocity of the blue mass after the collision is -0.235ms^{-1} . Kinetic energy of blue mass before collision 0.096J . Kinetic energy of blue mass after collision 0.00525J . Kinetic energy of green mass after collision 0.0747J

S22. When the small object hit the large one the momentum was conserved and the kinetic energy was also conserved. The sum of the modulus of velocities = the initial velocity.

S23. Before momentum = 10×2

After momentum $(8 \times 4) + (2 \times -6) = 20$

Momentum before = momentum after.

perfectly elastic i.e. is conserved.

S24. Momentum = 20 After momentum $(2 \times -6) + (8 \times 4) = (-12) + (32) = 20$

Momentum conserved, kinetic energy conserved.

Try making measurements that will help you decide how the speed of one mass (target) after the collision depends on the speed of the other one (projectile) before it and how it depends on their relative masses.

S14. Kinetic energy = $\frac{1}{2}mv^2$

A slight change in velocity will cause a large change in v square which means a large change in kinetic energy. velocity more important the velocity

$$\begin{aligned} \text{S15. } \frac{1}{2}m_1v_1^2 + \frac{1}{2}m_2v_2^2 &= \frac{1}{2}m_1u_1^2 + \frac{1}{2}m_2u_2^2 \\ \frac{1}{2} \times 10 \times 1^2 + 0 &= \frac{1}{2} \times 10 \times 0.37^2 + \frac{1}{2} \times 2 \times 1.37^2 \end{aligned}$$

S16. Speed of small mass after collision is proportional to the initial speed of the larger mass.

$$100 - 37.2 \qquad 0 - 27.44$$

The velocity of the larger mass is 37% of the initial velocity after the collision when the mass of the first object is 5 times that of the smaller.

S17. $u_1 + u_2 = v_2 - v_1$

S18. Staring velocity = $v_2 - v_1$

$$u_1 + u_2 = v_2 - v_1$$

Proves that momentum is conserved.

S19. The collision has lost in kinetic energy, it has also lost momentum.

The velocity of the small is $xms-1$ more than the larger one where x is the initial velocity of the large mass.

S20. The collision has lost kinetic energy. The collision has lost momentum. The speed of the small mass is $xms-1$ more than the speed of the large mass where x is initial velocity of large mass.

S22. Speed of the first object after collision + initial velocity equals the speed of the second object after collision. When the larger mass hits the smaller. When the smaller mass hits the larger it is the opposite. momentum is not conserved when larger hits smaller.

S23. Small masses colliding into mobile large masses result in little mass moving back the opposite way and the big mass moving in the direction of which the small mass came.

S24. Small mass hitting into immobile large mass will result in the large mass moving forward at a lesser velocity and the small mass bouncing back (unless small mass' velocity is very high). Large mass hitting the immobile small mass will result in the small mass moving at a velocity greater than the original speed as the large mass, in the same direction. The large mass will move in the same direction at a smaller velocity than it originally had. If however the initial velocity of the large mass was very small it could bounce back. It is all a balance between the masses of the two objects. The greater the mass of moving object the slower it will have to travel to bounce back. The smaller the mass of the moving object the greater velocity it has to have to not bounce back.

Q2: Post test questionnaire

What do you think of the CirclesColliding simulations? How satisfactory do you think the interface (what you see on the computer screen) is?

S13. The interface is very satisfactory and kept very simple and very easy to understand.

S14. The program helped with real life simulations and made the problem easier to understand because it showed us all the necessary figures e.g. speed before/after. This program helped us to look at the problem in a reasonably simple way which was made easier to understand.

S15. The simulation is laid out clearly so that it is easy to see all the information at once. However it is not so easy to see general relationships because only the current data is visible on the screen. The simulation is easy to control and the interface does not get in the way.

S16. The simulations were easy to use and allowed the user to find helpful information on the masses at any stage of the collision. This is aided by a simple but effective interface.

S17. The simulations were very good. The interface was easy to understand.

S18. The simulations are good as you can actually see what is happening and return to specific points along the line that you want to see again. The interface is good as it is simple so it is obvious what is happening.

S19. I think that the simulations were interesting, it showed the system's response to amount of speed inputted. And it showed how much it dropped in speed.

S20. The information on the screen is very basic which makes it very easy for someone such as myself to understand. It definitely was clear and the graphs etc. were easy to read. You only get the information which the programmer has put in.

S22. The simulations are very user friendly and make the subject interesting. They show up points you may not always notice.

S23. I preferred it to reading information from books because you could see the activity actually happening in front of your eyes.

S24. I liked using the simulation. I think that modelling theoretical situations with you could not demonstrate in the classroom would be a good learning experience in schools id used.

How satisfied are you with how you used the CirclesColliding ?

S13. Could have utilised the software better. Option to magnify graphs and manipulation of values of masses would be most helpful as would some kind of bubble help such as the one that could be used by the Macintosh and it is on its O/S

S14. I think we used it well. We changed the speed of the masses so we had some results to look at. This made it easier to tackle the problems which we faced.

S15. I do not feel I used the simulations to answer the questions efficiently as I could have. The first questions were easy to answer using the simulation.

S16. I think the simulations were used well initially but effective use of its facilities was not made for the last question.

S17. Very. It was very easy for me to explore the simulations so I gained maximum use from it.

S18. I think that we could have used more examples and seen how different velocities changed the outcome of the experiment, but I think that we did quite well.

S19. I was very satisfied with the simulations.

S20. I am very satisfied. I first imagined that I would be able to understand what I was doing, however this was not the case.

S21. Quite pleased, it is quite easy and I do now understand conservation of momentum better.

S22. The simulations were easy to use and I am pleased with the performance in them.

S23. I am satisfied because I have learnt some new things using it.

S24. I found it easy to use and understand.

What do you feel you have learnt after using the CirclesColliding simulations?

S13. I feel I have learnt how to use the simulations and manipulate data on simulations better. Using software like this is very useful as it gives you a chance to simulate models of collisions and see how they work.

S14. I've learnt that a problem can be made easier by using computers rather than making the experiments ourselves. It made it easier to tackle and more interesting to think about. It also made it more accurate.

S15. I feel that I have learnt what happens in simple collisions whereas before I would just have guessed.

S16. I have learnt and refreshed my memory upon the basic laws governing the collision of particles.

S17. I have learnt a lot more about momentum and collisions than I book in during my GCSEs.

S18. I have learnt more about collisions and the conservation of momentum after a collision and I think that I will find it easier to visualise them in my head now.

S19. I have learned that when a smaller object collides with a larger object the larger object will gain some momentum. That when a larger mass hits a smaller object that the larger object loses some momentum.

S20. I have learnt how to use computers to relate to real life situations and it definitely saves time and is probably much more accurate than carrying out an experiment.

S21. That in perfectly elastic collisions the momentum is not always conserved as I first thought.

S22. They have allowed me to experience further knowledge of collisions.

S23. I have learnt more about collisions e.g. collision 3 , the smaller mass moves with a higher velocity than the original velocity.

S24. That 2 equally massive bodies when moving towards each other with separate velocities can bounce back in the opposite directions at the same velocity to conserve momentum rather than becoming immobile. That the simulations could be useful in schools.

S25. I liked working with the non-point mass. I didn't explore this sort of problem at school.

S26. That there is no minimum speed.

Do you think that working with CirclesColliding helps to understand better conservation laws and collisions? Yes/No. If yes can you say how?

S13. Allows you to visualise a model of a collision and allows you to alter the conditions and scenarios of collision which is very useful in helping to understand conservation laws and how they apply in realistic situations.

S14. It's easier to understand than using books and you can actually see the examples happening without having to actually set up the experiment. It gave me a better understanding of conservation laws and collisions.

S15. Yes .They help to give a clearer understanding of collisions. I would need to use it more to understand conservation laws in more depth.

S16. It represents graphically how momentum and kinetic energy is conserved which allows the user to realise these laws more easily. The information given about mass and velocity at different stages of the collision also allowed me to understand simple collisions in great detail.

S17. It was better than practical experiments because I had a lot more control over the conditions so I could get to grips with it and understand the laws much better.

S18. You can see what is happening, and use the figures given to work out the principles of collisions. But computers cannot be used for all of the lessons because they are 2-d.

S19. It shows what will happen if you increase the speeds of masses without all the lab equipment which will probably not work anyway. It also allows you to run through the collision and plots accurate graphs.

This all helps in the understanding of laws and what happens when things collide.

S20. Often in physics experiments the results are inaccurate. The computer simulation allowed us to calculate/find relationships in the collisions of masses which we would probably not find elsewhere.

S21. By modelling real situations where the theory applies i.e. there is no friction on a computer screen.

S22. By showing exactly what happens to momentum and direction etc. and allowing the user to work out kinetic energy for the system. This allows an understanding of energy conservation to be found.

S23. Because you can visualise what happens on the screen, whereas books are not always clear and so you may visualise the wrong concept of the problem. However it would be better if there was a questions and answers section, because if you did not understand you could ask the computer and it would give you an answer. But overall I preferred using the simulation to reading information out of a book.

S24. Yes. I already had a fairly good understanding of conservation laws. It helped me to remember them however. The simulation is of bouncing masses etc. is normally how I try to visualise such impacts, however seeing it on a screen is more interesting than relying solely on calculations on paper.

S25. I could observe well the collision but I didn't get to notice the observation of energy. Conservation of momentum was easier to see. What I'd like would be a graphic plotting tool, so that I could check, e.g. v square, times time etc.

S26. It does not allow you to calculate very easily conservation of momentum and energy. Changing the mass might be fun.

T: Samples Interaction Transcripts

Students S15: Anthony and S16: Martin.

S15. Right. This is going down here. How much? Five? (Right slider)

S16. Let's stop it.

S15. Let's go back

[They look at the sequence again]

S15. Let's go to see their velocities, just before the collision. Where we have ten and five.

S16. After the collision they swap over. That's ten and that's five.

S15. Kinetic energy and momentum. Are they conserved?

S16. They must be. It's the same mass and momentum overall is conserved.

S15. Do we need to elaborate on that?

Collision 2.

S15. Sequence 2, logical progression, isn't it?

S16. Initial? you can't change the velocity of this one. The one on the right doesn't move.

S15. OK. Shall we start with 10 or 5.

S16. 10.

S15. Momentum of the first one is gonna be ... Shall we call these object one and two

S15. That's initially

S16. It's gonna stay the same after the collision.

S15. It's not accelerating very much. It accelerates in the first frame....Momentum of one is 2×6 , we know the values and we can pop them in the kinetic energy as well.

S16. Is it constant?

S15. That's what we will try to find out. 2×6 equals 12 and...

[They calculate]

S15. This is minus twelve so it is always conserved... The initial momentum is 20? Yeah?

S16. ...

S15. Come on.

S16. Yeah. OK.

S15. And here it is also twenty. Yes? That's after. Total momentum for both, before and after is conserved. Yeah?

S16. Yeah.

[They write up their findings]

S15. Kinetic energy is... I'm just thinking it through.. So before is...

[They calculate kinetic energy before and after]. So kinetic energy is conserved.

S16. It makes sense though. Doesn't it?

S15. We just needed to prove it though.

[Third question]

S15. Let's have a few goes with different speeds with the original simulation. We've got to.

S16. Let's try different speeds to find a relationship.

S15. It says how it depends on the speed of the big one before the collision... So how we will change that speed.

S16. Or the relative speed.

S15. See if we can change the speed of the big one to help us a little more. You can't...

S15. Let's run it. Stop it there... After the collision it's ten more. Let's change it. This was half of the last one. We halve the initial velocity and that halves the difference in speed. Does it?

S16. No...It will be a square relationship... maybe. Energy is conserved, mass is the same. I don't know, I'm just improvising.

S15. Let's reset once more.... It's always 37% of the initial thing.

S16. Is it? Are you sure? This goes up in 1.37 and this goes up in 0.37.

S15. 37 to 1. If you divide it.

S16. That's the initial velocity but what 37 has got to do with it?

S15. Well?

S16. How does this one relate to the mass?

S15. This one I am not bothered about.

S16. how can you ... I mean this ...

S15. It's a relationship with the combination of the two masses we are looking for... I think. It's not immediately obvious what kind of relationship though.

[They run again the third simulation].

S15. We've got a force here.

I don't know ...It's always 37% of the larger one.

S16. If it's consistently 37% of what it started with.

S15. Why does it give 63% of it's original velocity to the small one. Why that initial relationship.

S16. What proportion of the momentum would that be? Would that be a quarter?

S15. Maybe some kind of square relationship.

[They swap from simulation to simulation, they open the menus of CC trying to find clues. They even try assigning a force to one of the masses.

S15. Why 37%?

S16. [Looking at the bar graphs]. Is this the same?

S15. The only difference is that you look at bars instead of numbers to find how much it represents, the actual figure.

S16. It's looking nice though.

S15. Just looking is not what we need right now.

Students S19: Gordon and S20: Peter

S20. This one (graph function) will record velocity, won't it?

S19. Yes...same masses. They are travelling at the same direction at the moment.

S20. Change the velocities.

S19. That's going down. Set velocities...

S20. If that one is zero (right one).

[Try to understand how the change of velocities affects the motion of the masses].

S19. That one adds speed to the other one which gets extra momentum.

S20. [Look at digital counters. They write down their measurements]

That's what happens. The momentum is conserved...Did you reset that?...That's the perfect elastic collision. both the same mass, both the same velocity in the opposite direction.

S19. Yeah.

S20. In this case they will never collide. They have the same velocity in the same direction.

S19. Yeah. In all these cases kinetic energy and momentum are conserved...How many times shall we run it?

S20. Velocities are transferred in a way, because this one hits this one (right).

[They calculate]

S20. Next one. Small and big mass. Small one travelling and hitting the big one... I didn't expect the big one to move. I put down that it might move.

S19. I put down that it wouldn't move actually.

S20. But it depends on how heavy it is.

S19. Can you increase the mass of this one?

S20. No, you cannot increase the masses...It transfers the energy and some of its velocity...The momentum is not actually conserved.

S19. No, it's transferred.

S20. Kinetic energy is conserved. It's got negative velocity. I don't know...

S19. Ten, it's going to bounce back, look.

S20. Yeah....That's it. Do before and after, just as we did.

S19. Before...

S20. It's gonna bounce back.

S19. Analyse the situation. It starts with 10m/s. This one then revs back away. It's - 6. That's 4.

S20. What was the -6? so the total kinetic energy before and after is conserved. But is the momentum? ...Momentum is going this direction as well, isn't it?

S20. Momentum is not conserved at all. Momentum is gonna be negative.

S19. Yeah.

S20. Unless you don't take into account the sign, which direction is going to.

S20. It's not perfect elastic.

S19. I suppose so.

Third question

[Read the task].

Right...I put the they would be joined together in one.

S19. Increase the speed. (Maximum). That's ten.

S20. Put it back to 5. Just to see if it will end up with six.

S19. No.

S20. No. This one has more kinetic energy to start with.

S19. The second has?

S20. Yeah? The total kinetic energy is more...

S19. The one (big) doesn't retain 10m/s. This goes down to 7.1. This one has none and ends up with 13.

S20. Total kinetic energy is 500.

[They calculate total kinetic energy of masses before and after.

S20. 500 exactly. it stays exactly the same.

S19. Yeah.

S20. What have you done?...Definitely lost in kinetic energy.

S19. And lost momentum.

[They read again the task].

S20. Say... change the speed of this one (big mass), ten more than that.

S20. Depends on the...

S19. Now five...

S20. One more (m/s). 1m/s more than the...x m/s more where x is the speed of the big glider

S19. x of the small glider.

S20. So if you know the velocity of the large glider before and after, you can work out the velocity of the small.

S19. Plus whatever.

S20. If you are told that, then you can work out the relationships.

Students S23: Philip and S24: Nigel

[Collision 1]

S23. This one's got the negative (1), (2).

S24. O.K. that before then. Before 10kg. Which way is negative?

S23. That way is negative [to the right]. (3).

[Calculate]

S24. What happened to kinetic energy and momentum in this collision?

S23. They are conserved.

[Calculate total momentum and kinetic energy]

S24. This is before or after? [pointing at the digital counters]

S23. This is before and this is after.

S23. O.K. It's elastic. Before we've got momentum. The masses are the same, it's two of them.

S24. Velocity is the same.

[Collision 2]

[Read what the task asks them to do]. (5).

S24. Before...[They calculate momentum before]. After you've got... it's -6.

Momentum conserved... So we have the big moving at...

[Collision 3]

S24. From the elastic collision 2 we had a small mass hitting a big mass. And the small mass tended to bounce back.

[They spend a lot of time not talking but working individually. more paper sand pencil task after watching a few times the sequences (visually)]

S24. If you have a high speed. It doesn't have to be negative.

In the same direction. The large mass in the same direction. The smaller mass... Basically you have a large object hitting a small object. The small object bounces back unless it's going very fast and with a large object hitting a small object, the

Users S25: Maria and S26: Rick

S25. Masses are 1kg each.

S26. You have the sliders by which you can control the speed of the masses (velocity and direction). you can have digital, graph, bar.

S25. How do you set the direction?

S26. Run the simulation first?

S25. What about the direction?

R. That' all you have sliders and the two masses. You must find out yourselves.

S26. Same direction.

S25. OK we want another direction. Could that be the tangent?

S26. Maybe. Try... obviously that's 90 degrees and zero is 0 degrees.

S25. Yeah. Lot's and lots of different directions where they would collide.

[run the simulation with a set of directions which indicate that the masses will collide but they do not].

S25. Ah! I didn't think of it.

S26. Or can you imagine, if this one is going very slowly it won't hit the other one.

S25. How can we establish the initial speed if we wanted one to go there and the other one there. Well the minimal speed, this one here, let's see, they are different but they collide and get different directions.

S26. Momentum. I guess you don't have to say how long for this and this to travel.

S25. Exactly. But then you should get the dimension off the ball but it's not written anywhere.

S25. Do you think we should just try it, since we haven't got the numbers?

S26. I guess so, we can't do anything else.

S25. Four is fine, but they talk about initial speed and the direction of the balls, it's difficult to get the speed, they always collide.

S26. Because these are starting at the same distance from the centre.

S25. Yes. Now if one has got 750 the other has....? We have to find out the proportions between them, the velocity, right?

S26. If you run, you will find what percentage.

S25. Oh, OK. So 7 and 1/2 and 4 was...

S26. This one wouldn't collide, we definitely know that.

S25. oh, no. Reset.

S26. try 6.

S25. 6. It does collide. What's this thing running here, I didn't see it before.

S26. I don't know, maybe...

S25. 50. 7.5 and 4 and 10.5, there must be a proportion.

S26. Well, that's 55% of that.

S25. Yeah, but it's 55% of half.

S26. I don't know.

S25. The thing is... This one can not reach this position. It's more complicated than that.

S26. Look they do overlap but they don't actually collide.

S25. I have never solved this problem before, you definitely need to know the radius.

S26. Well, that's research!

S25. Because if it's faster it will collide... No... I want to see how big they are to collide... You see this one went all the way here to collide and this one...

S26. You see it's not actually colliding right on the edge, it's gone a little bit further...

S25. Now the other one, the one that was $5 \frac{1}{2}$.

S26. It's not quite colliding yet, it's just touching.

S25. But this one has gone this distance, here. This distance here is less than the radius, the centre of this ball is not in line

S26. sure, so what's the closest approach.

S25. The initial speed and direction, there are so many different directions.

S26. We've only changed the direction of this ball, not the other one.

S25. If this goes into...

S26. Change the directions.

S25. OK, this one won't collide.

S26. put it at 45 degrees.

S25. If they have the same direction they will never collide.

S26. If they run parallel to each other.

S25. Yes.

S26. We need different directions.

S25. Let's make the directions slightly different... Same velocity.

S26. Are they coming closer together.

S25. But we can't see if they are going to collide or not.

S26. We need this one to be larger than that one for them to collide, because if they are equal they run in parallel.

S26. You really need to know the separation on the x and y axes.

Because if we looked at the velocity at the x direction and we ... And

look at the y direction to see if they are in the same points... We need to know the distance, the one from the original.

S25. Do you think you really need to know that, we're not talking about points, it's got dimensions.

S26. True.

S25. Sometimes it hits here and sometimes there... So it's not as simple as a point.

S26. Let's click, it takes 10 clicks/frames, assume each is 1 sec, therefore 10m/s. so that's 1 sec, 1 m from start to origin.

S25. Maybe we can find the radius.

S26. Maybe.

S25. Is the distance the outside of the circle to the centre... We want to work out and do it. Travelling at 10m/s, travels in 0.02 seconds.

S26. So it's 0.02×10 .

S25. Yes.

IT: Interview transcripts**1**

R. What did you think of the whole experience?

S13. It was very good. It was very simple to understand and visually simple. You can manipulate a lot of the values, which is good, if you could manipulate the masses would be more of an option. Manipulating also the masses would have been a bit more of an option. I'd like to see features like bubbles (balloons) explaining and making it easier to understand. It was a very good program.

R. What did you think of the questions, the actual tasks, were they difficult?

S13. They were quite difficult but not that difficult. The last one threw me a bit. The large mass versus the small mass.

R. What were the things you didn't like in this programme, you said you didn't like the fact that you couldn't change the mass in the simulation.

S13. Yeah, that could have helped. If you had better manipulation you could have better understanding and the questions were a bit hard to understand. e.g. the third question. About working out the momentum before and after I didn't know whether I had to apply kinetic energy as well. I didn't really know. Then I did work out that. I am not sure it did apply. Now what happens is the large object hits the small object. What happens the smaller mass goes off with at a faster speed than the combined speed of the larger mass before the collision, plus the larger mass after the collision which I didn't really understand because when you try to work out the kinetic energy...

Other than that the programme is very useful. In a classroom where they are talking about masses colliding. You can't imagine what they're talking about but if you see something like this you can understand what is going on and why things happen.

R. You can visualise situations.

S13. Yes you can visualise it. There are more advantages I think than in a classroom situation. If someone is tutoring or trying to show someone who doesn't understand then using this would be a really good bonus.

R. Have you done any collision experiments in the lab.

S13. Yes with trolleys, mass trolleys and air tracks.

R. How would you compare this simulation to...

S13. It's easier to set up and run and the situations are the same. You'd save a lot of time basically especially if you have a lot of errors in these kinds of experiments like when setting up reading errors. But you don't get that kind of errors with computers.

R. Would you trust the results from a computer simulation the same as the results of the experiments set up in the lab.

S13. It depends. If the programs and everything that make the computer is done very well, then I would trust the computer program more. With a computer you just have to run the simulation and use different velocities and you don't have different controls over the velocity, either when you are in the lab you don't have control over the velocity because you are just pushing it. You don't know how much pressure you are applying and how much force. There are many more advantages.

R. What about the graphs? Do you think graphs helped in realising what was happening?

S13. Yeah, but if it had some sort of option to zoom in and out, enlarge them. That would have been better still. Graphs were useful. When they showed the collision they seemed to change. If you get the change in direction then they showed the changes in direction.

R. Was there a problem in finding the correspondence between the motion of the masses on the screen with the actual graph?

S13. No. Not much but... if you had the option to enlarge the graph, have all the large scales it would be much easier to read. Other than that it was easy to read the graph.

R. There are other simulations, like this one (Multimedia Motion) that are more realistic like a video. Do you think that kind of simulation is more realistic or easier to understand?

S13. I don't know, You are only making it more realistic at the expense of a lot more memory as well. It would be just as easy to use that as it would be to use the other one. The difference being you see two balls colliding instead of two computer drawn objects colliding. So there really isn't much difference. The only difference is a whole lot of memory.

R. So, do you think that computer simulations like CC1 would help you understand collisions in real life.

S13. Yeah, I suppose, but if you had two cars colliding or a footballer kicking a ball then you could use it. With a video you could freeze frame and it is more complex (than a) simple drawing which is also easy to use, although sometimes it may be too simplistic. You could then estimate the velocity and the transfer of kinetic energy. But I think a simulation is better for situations in the lab and simple things in real life, yeah it's very good.

2

R. So what did you think of the whole experience? Did you enjoy it, was it all right?

S14. Yeah.

R. Did you think the questions were difficult, average or easy?

S14. The ones on the first page were a bit difficult, but once I'd done the simulation I understood it all. Then it was pretty easy.

R. So do you think the simulation helps someone who doesn't remember or needs to refresh their memory about the physics of collisions and colliding bodies?

S14. Yes. Because the first time I did it I didn't really understand it was just about trolleys going down ramps and stuff. Because you can change the velocity of the other. You could control everything about it. It was a lot easier to understand it.

R. This simulation (MM) follows the same principle as the one you used but this is more realistic like this motor bike guy collides with this guy in a car. The idea is instead of something which is just two abstract spheres colliding on computer screen, we can have something realistic. Would you prefer to use a simulation like that? How would you find it in terms of difficulty?

S14. It might be more difficult.

R. Why is that?

S14. Because with spheres you can concentrate just on that but when you have two different things like a car and a motorbike it's more difficult because you might get confused because it's a different shape. You have lots of things around it so you get distracted from what's really going on. The plain thing of two circles and an arrow is much easier.

R. What about the simulation itself. Is it something you would like to change?

S14. No.

R. You can't think of anything.

S14. No.

R. What about the graphs? Did you use them a lot?

S14. They were a bit small. I wasn't sure what all these bits were.

R. Did you use them a lot?

S14. No, not really. If maybe they were bigger or made more clear what the different traces were. Because it was small, it was difficult to see where everything was on the scale. So it was much easier to look at the table down the bottom.

R. So do you prefer working with the counters at the bottom?

S14. Yes, It was good being able to run it back and forth through it, because you could see how it changed when it collided. On the graph you couldn't really see that.

3

R. Did you enjoy that at all?

S16. I enjoyed it for most of the time. I got a bit aggravated when I couldn't work out what the relationship was at the end but it was fun to use. It is easy to use, so I quite enjoyed it for that.

R. Do you think the questions were difficult or easy?

S16. No they were easy I think, if we were doing collisions right now in physics it would be more on my mind, it's just that I haven't done physics for a number of years, so I'm not quite up-to-date on everything, but they were reasonably easy, with the simulations you'd shown me.

R. Do you think this kind of simulation helps to visualise things?

S16. Yes... It doesn't teach you a great deal, particularly because it's about simple collisions, it's nothing in it that's difficult to understand but it... you get to see it graphically, why.... momentum and kinetic energy is conserved etc. and how the large and smaller masses... how the energy between them is transferred and you can just visualise it. It's easier to understand/ remember because of that.

R. It's a simple interface, circles moving on the screen. Do you think it would be better if it were complicated/something more relevant to the real world, for instance there is another simulation here which is that of a motor bike colliding with a car. Have a look.

S16. I think if you did that it would be more interesting for people who don't enjoy physics as much, if you wanted to interest them more. If you just want to answer something and understand for physics reasons... I think it (CC1) takes it to its basic level which is what you want for you to understand it better.

R. So you think that CC1 is easier to understand?

S16. Yes I think it's better.

R. Despite the fact that it's the same phenomenon.

S16. Yes. I don't mind seeing a motorbike crashing into a car. I'm sure it's amusing but in the end I prefer CC1.

R. What about the graphs? Did they help, did you use them a lot?

S16. No, not really. I think we used the numbers pretty much.

R. Because the digital counters were more useful than the...?

S16. Well, I mean that the graphs would have been much more helpful if the acceleration of the circles were done in more detail, as it was steady so acceleration wasn't so important in the simulation there was no point in the graph it is just as easy to read off from the numbers what a straight line is.

R. Do you think it is easy to watch at the same time the spheres moving and the changes in the graphs.

S16. Yeah reasonably easy. It's all simultaneous you can see when they collide, the graph on..., so it was reasonably easy to compare the two, yeah everything was easy to see because it's uncluttered. So you could compare the two. It wasn't like you had to watch one and then the other. This would have been more difficult. You could see it all at once.

4

R. So what did you think of the whole experience. Did you enjoy it at all?

S18. Yeah, it was a bit daunting. It was good. You could actually see what was happening and work out why it was happening.

R. Have you used any simulations before?

S18. I've used a lot of simulations for planets. The orbit of planets.

R. You watched on the computer screen planets moving around?

S18. Yeah.

R. But you had to do measurements or anything like that?

S18. No, not really. It was to do with putting satellites into orbit and what you have to do with it.

R. What did you think of the questions? Easy, average difficult?

S18. Some of them were a bit of short of daunting. But some were all right.

R. For instance the last one?

S18. Yeah it was a bit hard.

R. Have you done anything on collisions in your G.C.S.E.

S18. Yeah we have done quite a bit we had trolleys we put them down a slope and smacked them into each other.

R. You made them collide with each other?

S18. Yeah, to overcome friction. That is what is good about the computer, you don't have to deal with that.

R. Did you use the graphs a lot in the simulations?

S18. No, not really. I did a bit.

R. So you used more the digital counters of the velocities at the bottom.

S18. Yeah, it was easier to understand, you could actually see exactly where it was.

R. Did you use at all the graphs then.

S18. Yeah.

R. Could you see the correspondence between the movement of the masses and the graphs.

S18. Yeah, it's like when they hit it like changes on the graph completely it was quite good.

R. Do you think it helps to look at graphs, as well in motion?

S18. Yeah, you could actually see how it moved, it's quite good.

R. There are a lot of different representations, for instance instead of having two simple circles colliding on the screen. We could have something more sophisticated, like this one, a motorbike driver who collides with this man in the car.

S18. Oh, no.

R. You can also have this kind of representation, instead of watching two circles moving on the screen.

S18. No, I don't like watching people on motorbikes hit cars, because my boyfriend has a motorbike. The spheres are simpler. You can actually see the difference.

R. So you think it's easier to work with something abstract.

S18. Yeah.

R. But when you see something in the street in real life can you relate it to the circles you used in the simulation?

S18. Yeah, I think you can actually visualise and compare it to what happened to the circles and why it happened.

R. You mean you can apply this to similar situations in real life?

S18. It's like if you had two trains that went splat, you know what happened if you have seen the simulation.

5

R. What about the third task? Was it difficult or an easy one?

S19. I found it quite easy.

R. What do you think of the simulation?

S19. It was good.

R. What about the graphs facility? Did you find them useful?

S19....

R. So you did not use the graphs at all?

S19. Not really.

6

S20. The simulation? I quite enjoyed it. if I had been taught in this way from the start, it probably would be better than just reading from a book. Normally you know when you choose velocity and see what happens.

7

R. What do you think of the whole experience, did you like the simulation?

S22. Yeah, I did as I put down in my answer. I think I found easiest about it the change of values of anything you wanted. And there is no friction on a computer screen. So if I was to do that against a table in the lab there would be friction between my objects and the table. It was easy to do actually.

R. So you think that the only advantage in relation to the same experience in the lab is that there no friction. Are there any disadvantages? For instance do you think it would be more profitable for a student to work in the lab or just use the simulation?

S22. If they want to investigate the effect of friction obviously they should do it in the lab, if they don't want to have the hassle of finding equipment, having to set it up, running the experiment timing accurately, finding velocities from these, the use of computer would be better, because it does the whole thing for you.

R. There are other simulations, the simulation you used is a kind of abstract form of reality what I mean by that is that you don't have realistic looking objects you just have circle and arrows which move on the screen. So you have to use your imagination to find correspondences from past experience.

S22. Yeah, sure.

R. This is another simulation called Multimedia Motion and it does basically exactly the same thing as the simulation you used.

S22. I see.

R. Instead of having the circles moving on the screen. Do you think that kind of simulation would be easier to use or more difficult?

S22. More difficult I think because if you use the MM one, you must get calculations of whatever you can think, e.g. a car has four wheels, a motor-bike has just two, a motor bike can go faster.

R. You mean there are a lot of factors which were not included in the first one.

S22. Yes, if you just use these circles they are identical apart from their masses and velocities. So there are no reasons you can't come up with why you get these values, why you get these answers. Other than the different masses and velocities.

R. What about the graphs and the digital counters? Did you find them useful?

S22. Yes, I quite liked them, because they showed you instantly how the velocity changed and as for the digital counters when I was calculating to see if the momentum was conserved I didn't actually have to sit down and have to work out the velocities of the objects. It saved me a fair amount of time.

R. If you had to change something in the simulation you used would there be anything you would like to change.

S22. I 'd like to try the simulation with a lot of different masses. In the third one which was the one where the momentum was not conserved there was a question about how does the relative mass affect it. In the calculations I found this value of 6.464 which appeared every time. I would like to find out if this figure is specific just to the masses I used or is it constant for all masses, or see how the relative masses affect the final velocities or whatever.

R. What about the questions of the worksheet? Do you think they were easy or difficult?

S22. The first one with the two equal masses was easy. I knew that already. But the other two with the different masses one being

stationary at the beginning and depending on which one collided with the other one, I wasn't sure what would happen then. The second simulation I understand that I know that's the other one where the momentum is conserved, but I am not still overly confident where and why the momentum was not conserved. I have to find out what happens and see what effect the masses have on these values.

8

R. So what did you think of the whole experience?

S24. It was good. It shows you how it all works and gives you a better knowledge of how the collisions come apart and so forth... and... you can change the velocities and that sort of thing, that was good.

R. What about the questions on the worksheet?

S24.

R. do you think they were difficult/easy/average?

S24. The first and then up to the last ones. You could get around them I think, the relative mass bit at the end of the last one was tricky. I couldn't quite figure out what it was asking, apart from that it was OK.

R. If you had the opportunity to change something in the simulation what would that be? That is if you feel something needed a change.

S24. The masses! changes of the masses, when we came up to that constant at the end... we didn't know if that was specific to the masses on the screen.

R. You mean it would be better if it had varied masses.

S24. Yes.

R. Like you can vary velocity.

S24. Yeah. Yeah. Yeah, that's it. And it didn't take into account friction, did it?

R. So you would be interested in a simulation which took into account friction?

S24. Yes.

R. As you saw this was a simulation which was using abstractions, I mean instead of having real masses, or realistic looking masses, it just had those two circles moving on the screen. I'll show you another simulation, this is called Multimedia Motion. This instead of using those two circles on the screen, uses movies of real objects, a movie of a collision, e.g. collision between a motorbike and a car.

S24. Oh!

R. If we could compare this simulation to the one you used, which one do you feel would be easier to use and why?

S24. The circles are easier because they are different shapes and the different resistance forces and stuff. The circle models simplify it.

R. Do you think that the circles give you the same indication of what is happening in reality.

S24. No.

R. Why?

S24. Because of the shapes of the car and the motorbike. Perhaps where it hits the car, for instance with the two circles, one circle hits the other, with the motorbike it would hit the front of the car, instead of bouncing off it would change direction rather than...

R. The motor bike has two wheels and it depends on the position of the car?

S24. Yes.

R. But if it has nothing much to do with what is happening in reality, do you see any point in using the circles?

S24. Yeah, they show the forces involved and what happens, how it would go off. It gives you a model to build on.

R. Does it give you an indication of what really happens?

S24. You have to make certain assumptions with the circles, like masses and that sort of thing.

R. Do you think that the graphs and the counters were useful?

S24. The counters were, the graphs were a bit difficult to follow. You couldn't really see, you could see if there was an acceleration, when the two hit, but on the graphs it just looked instantaneous, on the second one you could see a slight change, on the third it just looked like a straight line.

R. Could you follow the changes between the graphs and the motion of the masses.

S24. Yes. That's it... like when they hit the velocity changed immediately, they stayed constant again as they moved along.

Appendix 7

Chapter Four Interviews

Interview questions..... 1

Interview transcripts 2

Appendix 6

Worksheet tasks: solutions

$$m_1 v_1 - m_2 v_2 = m_1 v + m_2 v$$

$$m_1 v_1 - m_1 v = m_2 v + m_2 v_2$$

$$m_1 (v_1 - v) = m_2 (v + v_2)$$

$$(v_1^2 - v^2) / (v_1 - v) = (v^2 - v_2^2) / (v + v_2)$$

$$v_1 + v = v - v_2$$

$$m_1 v_1 - m_2 v_2 = 0 + m_2 v$$

$$m_1 v_1 = m_2 v + m_2 v_2$$

$$m_1 v_1 = m_2 (v + v_2)$$

$$v_1^2 / (v_1 - v) = (v^2 - v_2^2) / (v + v_2)$$

$$v_1 = v - v_2$$

$$1/2 m_1 v_1^2 + 1/2 m_2 v_2^2 = 1/2 m_1 v^2 + 1/2 m_2 v^2$$

$$m_1 v_1^2 - m_1 v^2 = m_2 v^2 - m_2 v_2^2$$

$$m_1 (v_1^2 - v^2) = m_2 (v^2 - v_2^2)$$

$$v_1 = -v_2$$

$$m_1 v_1 + m_2 v_1 = m_1 v + m_2 v$$

$$v_1 (m_1 + m_2) = v (m_1 + m_2)$$

$$v_1 = v = -v_2$$

$$1/2 m_1 v_1^2 + 1/2 m_2 v_2^2 = 0 + 1/2 m_2 v^2$$

$$m_1 v_1^2 = m_2 v^2 - m_2 v_2^2$$

$$m_1 v_1^2 = m_2 (v^2 - v_2^2)$$

Task 3 of the work sheet

From the conservation of momentum and conservation of K.E. laws:

$$m_1 v = m_1 v_1 + m_2 v_2$$

$$1/2 m_1 v^2 = 1/2 m_1 v_1^2 + 1/2 m_2 v_2^2$$

$$m_1 v - m_1 v_1 = m_2 v_2$$

$$m_1 (v - v_1) = m_2 v_2$$

Appendix 6, Worksheet tasks: solutions

$$m_1 v^2 - m_1 v_1^2 = m_2 v_2^2$$

$$m_1 (v^2 - v_1^2) = m_2 v_2^2$$

$$m_1 (v - v_1) = m_2 v_2$$

$$v + v_1 = v_2 \Rightarrow v = v_2 - v_1$$

$$m_1 (v - v_1)(v + v_1) = m_2 v_2^2$$

By substitution:

$$m_1 (v_2 - v_1) - m_1 v_1 = m_2 v_2 \Rightarrow m_1 v_2 - m_1 v_1 = m_1 v_1 + m_2 v_2 \Rightarrow$$

$$m_1 v_2 - m_2 v_2 = m_1 v_1 + m_1 v_1 \Rightarrow v_2 (m_1 - m_2) = 2m_1 v_1$$

$$v_1 / v_2 = (m_1 - m_2) / 2m_1 \quad \text{or} \quad v_1 / v_2 = (1 - R) / 2$$

The two relationships determining velocities and directions after the collision are

$$v = v_2 - v_1$$

and

$$v_1 / v_2 = (1 - R) / 2$$

For sequence 2:

$$M = 10/2 = 5 \text{ and } v_1 / v_2 = (1 - 5) / 2 \text{ or } v_1 / v_2 = (1 - 5) / 2 \text{ or } v_1 / v_1 = -2$$

$$v_1 = -v / 2 \quad v_2 = v / 4$$

For sequence 3:

$$M = 10/2 = 5 \text{ and } v_1 / v_2 = (1 - 5) / 2 \text{ or } v_1 / v_2 = (1 - 5) / 2 \text{ or } v_1 / v_2 = -2$$

Interview questions

- What experience do you have of using simulations for teaching?
- What design features make a good simulation?
- Do you have any opinion about how realistic simulations ought to be?
- Is there any literature that you go to, when you want to design a simulation?
- Is there a specific simulation that you consider successful? Why?
- Are high fidelity levels in simulations interfaces necessary for understanding the processes involved?
- How transparent the learner interface has to be in order to permit a view of the underlying model? Can realistic simulations permit the identification of the underlying model?
- Is the level of fidelity dependent on the knowledge level of the learner e.g. high fidelity for novice students and low fidelity for experienced students?
- Is time fidelity (real time) significant for computer simulations?
- Is the level of motivation enhanced by a high fidelity level?
- Can the learner be helped by shifting fidelity levels during a simulation or a sequence of simulations?.
- Is 'hands on' instruction with real equipment or an interactive video the highest degree of fidelity?
- Is there any relation between fidelity and the domain of a simulation?
- Would combinations of the two variables (e.g. low fidelity-high complexity etc.) be beneficial for the learner?

Interview transcripts**What experience do you have of using simulations for teaching?**

1. In the computer lab.
2. My experience has been in the design, development and evaluation of simulations.
3. I have used a few in the classroom.
4. I have built a small science simulation which I have used for teaching, an educational program that I evaluated in a local school. I have also looked at most of the data collected in a Spoken language and new technology program which looked at students using simulations. So I have some other source of information. Most children were between 9 and 13. I implemented the first simulation in Hypercard to write it.
5. I have used Science simulations.
7. Of most interest to you would be my experience in evaluating students using simulations, although I was not their 'teacher'. I have evaluated students using both situational simulations and a process simulation. The two situation simulations were both designed by myself. 1) a simulation of students engaged in running for student school president and 2) a simulation of students learning about identifying features and behaviour of suspected criminals. My experience with process simulations was the evaluation of students learning about phase diagrams in metallurgy.
8. Design, development.
9. DM3 work . Also pilot work.
10. Design and evaluation.

What design features make a good simulation?

1. An important design feature is that the simulation must behave consistently, that is that it must behave in a way in which the student will believe it is correct, not erratically.
2. Engaging to the people, familiar, realistic, mapping to the everyday real world, extensive range functionality, degree of user control.
3. I think you should look at the whole context, the pedagogy and so on. But that's a different issue it's not the design issue. You have to consider how much you want to do with the simulation. It might not be enough to just have the simulation where you can change the variables and look at the result. You have to make predictions and compare the outcomes with those predictions.
4. If the question is about only the actual simulation and not about effective teaching, then I would say the ability for the simulation to introduce unexpected variables, especially in situational simulations.
5. It's a difficult question because it's a rather big question.
6. One problem with children you see with simulations is that they can be used as a kind of game without reflection, very rapidly gaining instant feedback.
7. Simple and clear interface. Should show something that can't be seen easily in the lab and it should help students to visualise.
8. You have to record these predictions, pedagogical issues really. You don't want to clutter the screen, you want it to be very clear, a simple interface, a clear interface, but also as part of the simulation, but also as part of the screen you want some kind of recording of the previous interactions, graphs perhaps or tables or something like that.
9. Good graphical output.

10. Good graphics, showing relevant, important points.

Do you have any opinion about how realistic simulations ought to be?

2. I don't think there is a general answer to that.
3. I am not sure if this is the right question. Because I think that this should relate to what you are teaching and the simulation is to guide learners towards the correct use whatever representational language and the correct use is obviously the desired educational use, the outcome in your educational evaluation of the exams, essays. Often you find that basically teaching people, guiding people towards a kind of discourse and the correct use of symbolic representations. So the question of realism is almost irrelevant.
4. The use of highly realistic simulations for adults can be fairly complex in early learning where there are many variables to keep track of (such as in Flight Simulators) which I believe can actually interfere with one's ability to build an appropriate mental model of the processes and relationships interacting in the simulation.
5. It's not a straightforward question.
6. It is highly dependent on the audience. For example, for young children I think simulations which are more like microworlds, which use unreal environments like fairy tales or space analogies can be very effective.
7. My experience has been in designing simulations based on fairly traditional instructional design principles, which I actually am not certain are the best to follow.
8. You try to draw children from the normal everyday concepts ether normal everyday language to the academic context, the academic use

of the language. you want to put the features that will help you to do that, Realism to the real world is a secondary issue really.

9. You must move from the perceptions of the learner in the subject area to the version of reality you want to teach. So obviously the level of reality is very important as to how to interpret whatever interface you have.

Is there any literature that you go to, when you want to design a simulation?

1. I try to integrate general principles of design, like practice and feedback, and also try to use gaming techniques to engage the learner, using such strategies as unexpected variables, keeping scores for attempts (especially for problem-solving), providing information about the decisions and paths the learner has taken for motivation and feedback, competition with other learners.

2. My experience has been in designing simulations based on fairly traditional instructional design principles, which I actually am not certain are the best to follow.

3. Theory of educational software.

4. Malone is useful to consult. Also theory on simulation computer games.

6. The literature I was going to recommend was the theory for designing interfaces was Michel and Tisby.

9. Not really.

Is there a specific simulation that you consider successful? Why?

3. The simulation which is one of my favourite pieces of educational software and that is the Carmen Sandiego software in which students play the role of a detective, garnering information from clues in order to find the thief. It is highly motivating and requires the learner to engage with a lot of information. I prefer the older version in which the learner used a book as reference to the various countries and flags.
4. SimEarth series. I have watched a half-dozen children working together to build simulated worlds for hours with this software. Because the underlying model is sound, it allows the learner to build a realistic model of how their decisions can result in a successful world or a disaster.
5. Flight simulator, because it was very realistic, provided extensive user control, it was not static, it felt like you were in motion.
6. Sim city. Particularly effective. It's successful. It's realistic, it reproduces the different processes involved in a city. You can construct a town from scratch given the maps. It is a combination of a simulation and a game, you get feedback.
8. CD-Rom disks.

Are high fidelity levels in simulations interfaces necessary for understanding the processes involved?

1. Low fidelity like a dot moving on the screen and a very high complexity like friction and a complicated way of the way the dots are moving on the screen, like having a collision which is not a linear one.

2. High fidelity levels will complicate the physics of the simulation.
3. Now that you point out the difference, I am a bit curious as to the interaction between fidelity and complexity. I only assume that as the fidelity is increased, so too is the complexity. I would be interested in your ideas on that.
4. No, anyway, as I said before it is sometimes appropriate to present different kinds of worlds to allow learners to interact with processes which you want them to generalise to other worlds.
7. In fact it may be contrary to what we want to achieve with sims i.e. drop people from this rich context to isolate the things that you think are important when you move from the real life version to the physics version by abstracting key features”.
8. Not necessarily
9. I am not sure if the question of the physical appearance of the simulation is relevant.
10. If we are talking fidelity as appearance similarity to appearance in a real world that wouldn't be an issue in the same way, actually the only point of fidelity in terms of making it look similar would be to encourage novice learners to feel happy but I don't feel that is what you mean.

How transparent the learner interface has to be in order to permit a view of the underlying model? or

Can complex and realistic simulations permit the identification of the underlying model?

1. Hm....I believe it is the behaviour of the simulation which provides the understanding of the underlying model in most cases. Although as I recall the quite complex simulation of PowerSim, I did find it

helpful to view how the underlying model was running through my 'worlds'. So I am not sure about this.

2. Yes

3. If you send a rocket to the moon you will use relativity theory only at a higher level, you won't use it with primary school children. So the complexity will be determined by the pedagogy not by anything else.

4. No.

5. No.

7. Transparency in interfaces is really a different issue altogether in my mind, where I want to see interfaces which do not hinder the use of a system, but I don't see transparency as 'hiding' something from the learner.

8. Yes.

9. The interface is a mirror of the underlying model, it is the behaviour of the simulation which provides the understanding of the underlying model in most cases.

Is the level of fidelity dependent on the knowledge level of the learner e.g. high fidelity for novice students and low fidelity for experienced students?

1. Yes, I believe fidelity should progress as the learner progresses with the model of the simulation. This is pretty standard simple-to-complex stuff.

3. It depends on the level of the learner.

4. Yes.

6. Yes.

9. High fidelity for novice students, low fidelity for advanced students.

Is time fidelity (real time) significant for computer simulations?

1. Yes, the ability for the time to speed up to allow the viewing of long processes, is a very advantageous feature of simulations.
2. Having real-time experiences with simulations is part of the building of a correct mental model of temporal relations.
4. Not always (not when motion in space is simulated)
5. No.
6. No.
7. Not for long processes.
8. No, Not for slow phenomena.
10. No.

Is the level of motivation enhanced by a high fidelity level?

1. As long as the learner is prepared from a knowledge point of view, yes.
3. High fidelity gives some sort of contextualisation, linking students, showing them the relevance.
4. No.
5. I think for advanced students the high fidelity level would enhance motivation. However, for the learner who is not ready it could demotivate them.
6. Yes.
7. In Friction Worlds we have a high fidelity interface, Hoovers that come out and do things. I don't think this kind of fidelity helps them to understand the concepts very much, it's only motivational.
8. No.

Can the learner be helped by shifting fidelity levels during a simulation or a sequence of simulations?

1. Maybe.
2. Yes, progressive levels of realism which might also provide different views of a model (i.e. functional, descriptive) could be of benefit in learning.
3. Yes. to move from high fidelity to low fidelity can be helpful, since you want to teach the correct representation systems, diagrams etc.
4. What you want to end up with is a formalism down to the abstract entities, mass, the distance. You want to draw learners from the high fidelity stuff to the high complexity one. But you cannot find an everyday context in quantum theory. You cannot really move from every day events to the underlying quantum theory.
5. Yes, when teaching a concept in a way that it transfers to everyday context., or when moving from the perceptions of the learner in the subject area to what has to be taught.
6. Yes.
8. No.
9. It is sometimes appropriate to present different kinds of worlds to allow learners to interact with processes which you want them to generalise to other worlds.

Is 'hands on' instruction with real equipment or an interactive video the highest degree of fidelity?

3. Yes, but an experiment is also an abstraction.
4. No.

5. I would answer that real equipment has a higher degree of fidelity than a second-order representation using video.

6. Yes.

7. Yes, I am not sure if you are asking this to test my understanding or use of the term fidelity or if you seriously want to know what I think.

8. Even an experiment or setting is an abstraction, an idealisation, a simulation of a real phenomenon.

9. Yes.

10. Yes.

Is there any relation between fidelity and the domain of a simulation?

1. Probably, but I believe that is a research question.

2. Situational or role-playing simulations are not domain-specific, nor are process simulations.

3. I am more comfortable with considering how different goals and audiences for whom the simulations are intended affect the fidelity. I wouldn't think that whether a domain is chemistry or biology somehow determines the required fidelity.

4. No.

6. In complex domains, fidelity may be taken too far, high fidelity misleading.

8. Depends on the learner level.

Would combinations of the two variables (e.g. low fidelity-high complexity etc.) be beneficial for the learner?

3. I rather doubt that you will get a clean interaction such as high fidelity and low complexity combinations. The level of description would require much more detailed understanding of both elements.
4. They are both interacting continuums, where I think it would be interesting to attempt to locate various successful simulations.
6. I get the impression from the way you have presented these questions that you are somehow separating these elements into a) fidelity is an interface issue and b) complexity is an underlying model issue.
8. The simple answer must be of course, both elements properly understood and designed will benefit learning.
10. That is also a research question which I believe is the intent of your thesis.